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Johansen

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(54) **STRAIN WAVE GEAR WITH OUTPUT FLANGE AND INTEGRATED ENCODER**

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See application file for complete search history.

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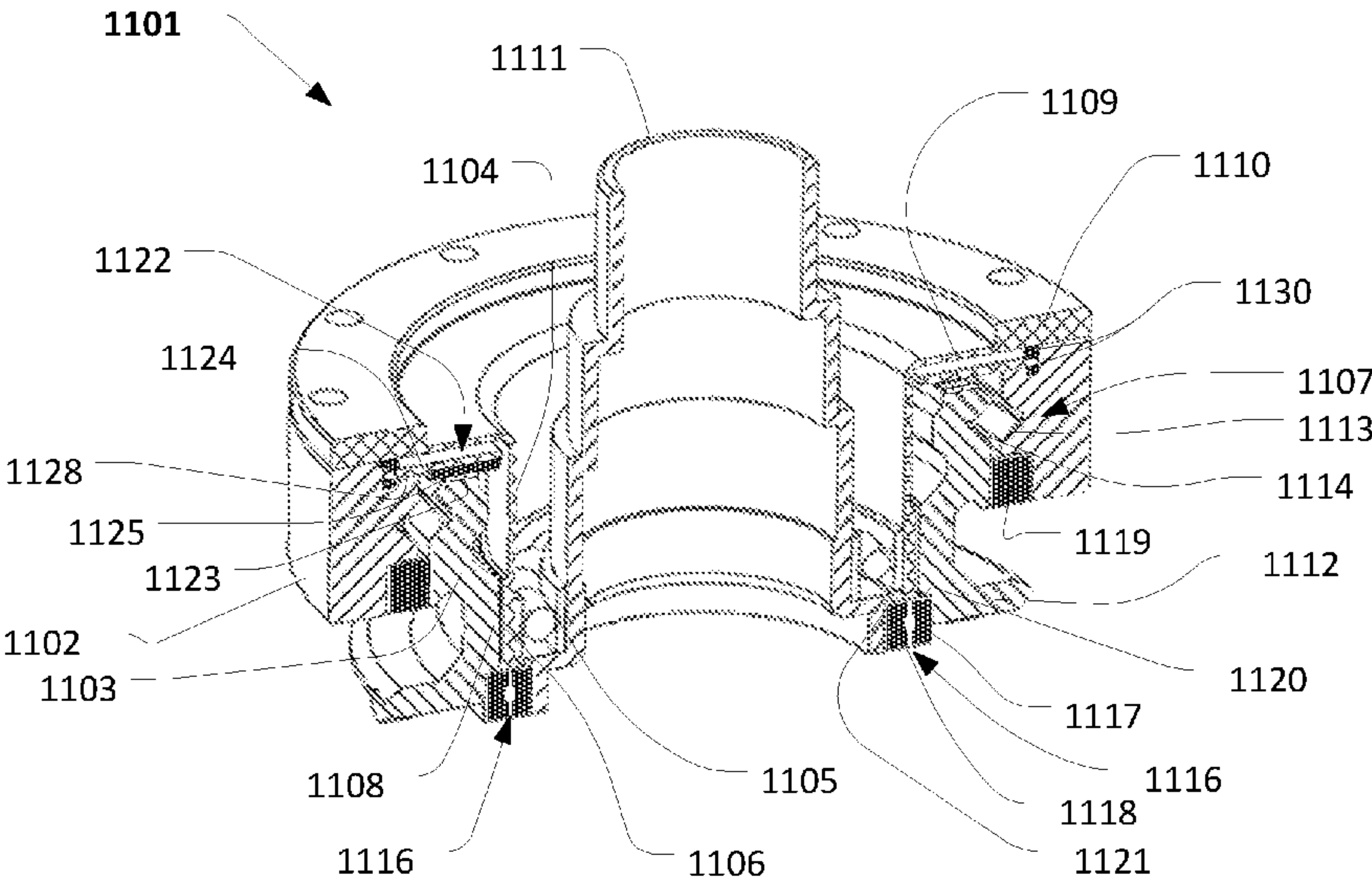
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(57) **ABSTRACT**

A strain wave gear includes an outer ring and an inner ring rotatably arranged in the outer ring. The inner ring includes an internally toothed gear and a flex spline is arranged in the inner ring and includes a flexible part that includes an external toothed gear. A wave generator is rotatable in relation to the flex spline and is configured to flex the flexible part in a radial direction to partly mesh the external toothed gear with the internally toothed gear causing rotation of the inner ring in relation to the outer ring. A part of the inner ring extends out of the outer ring and includes an outwardly protruding output flange. An encoder reader can be disposed on the outer ring and an encoder track can be disposed on the inner ring. A robot joint that includes the strain wave gear is also disclosed.

23 Claims, 10 Drawing Sheets



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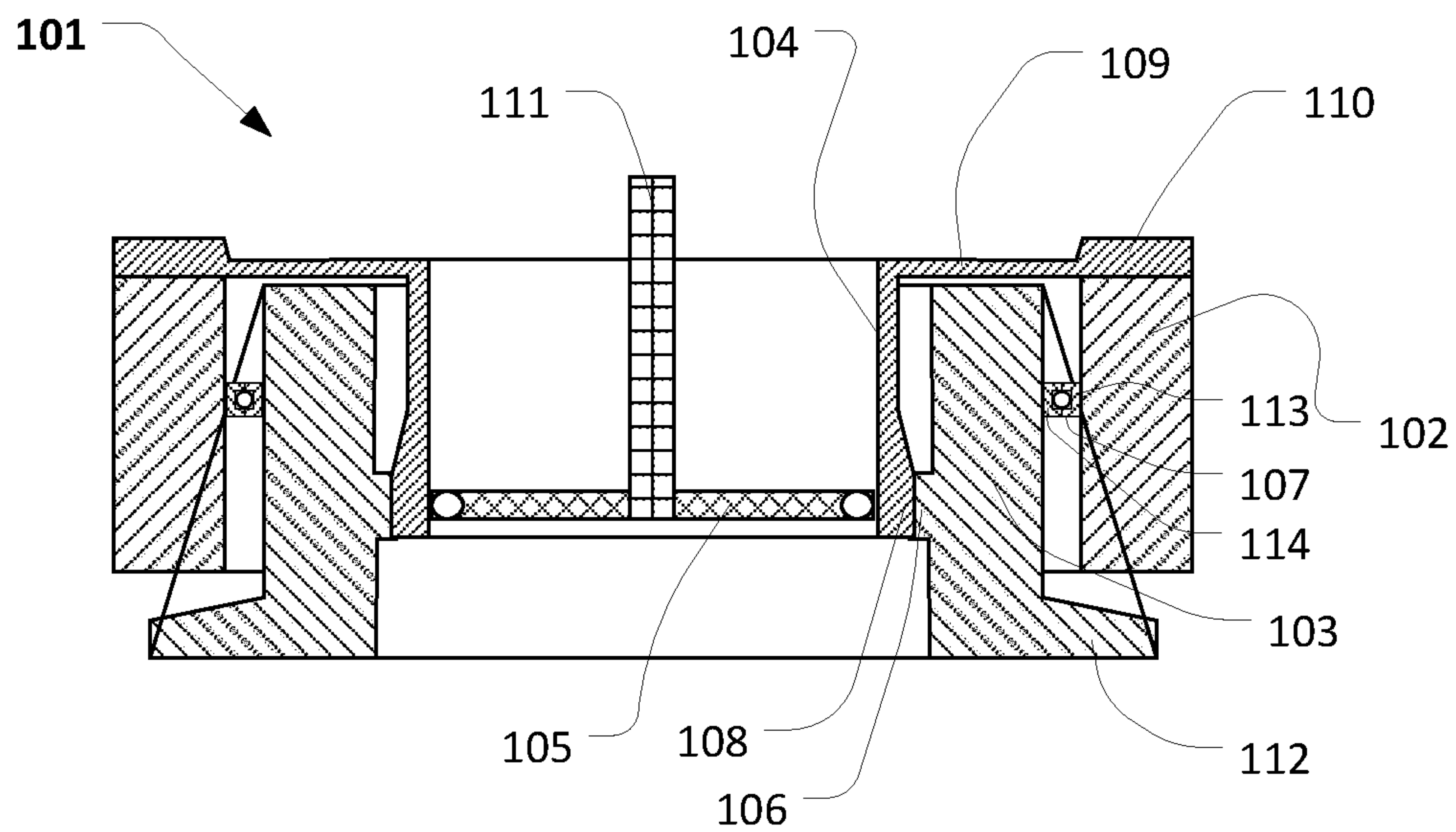


FIG. 1

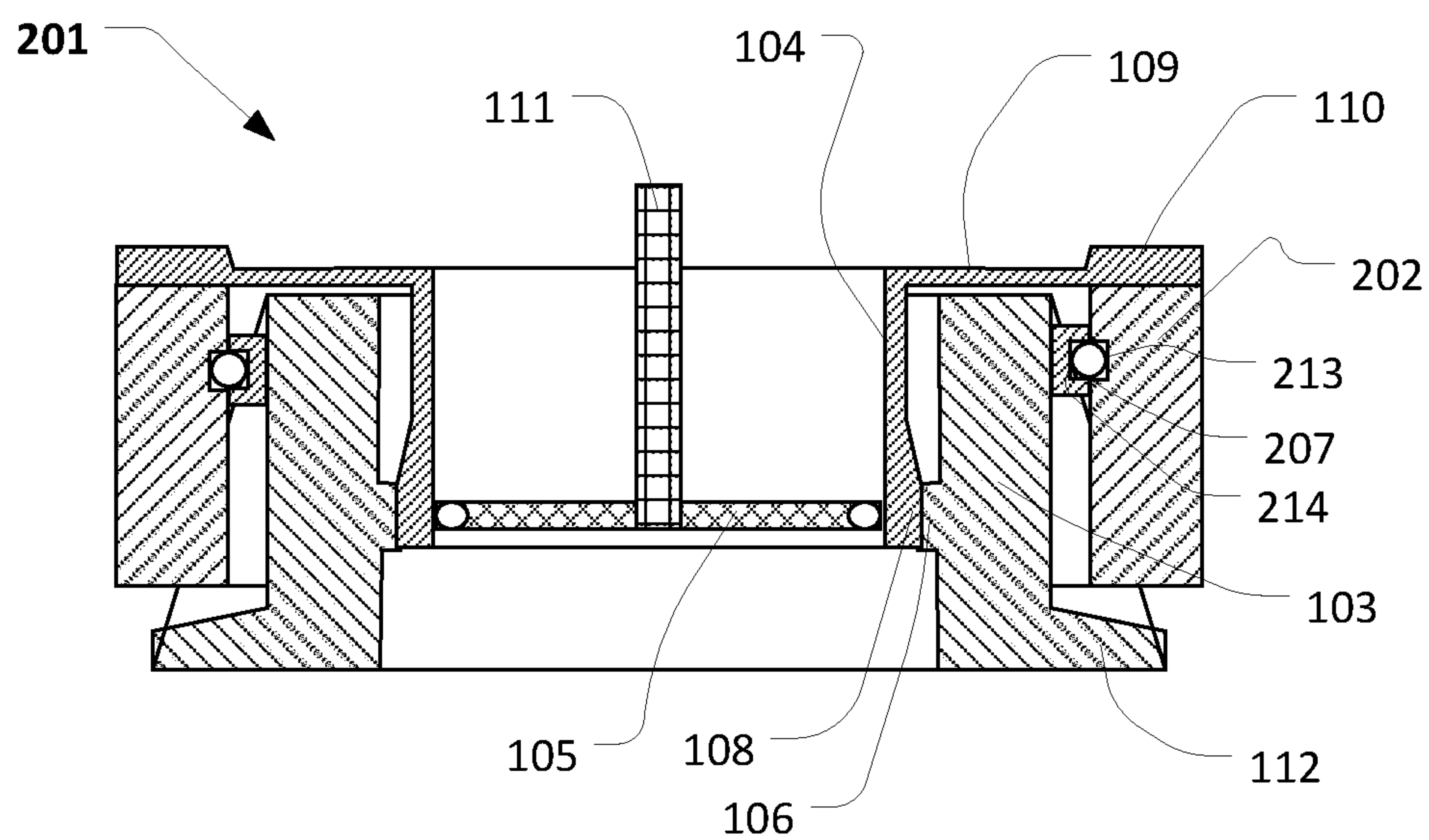


FIG. 2

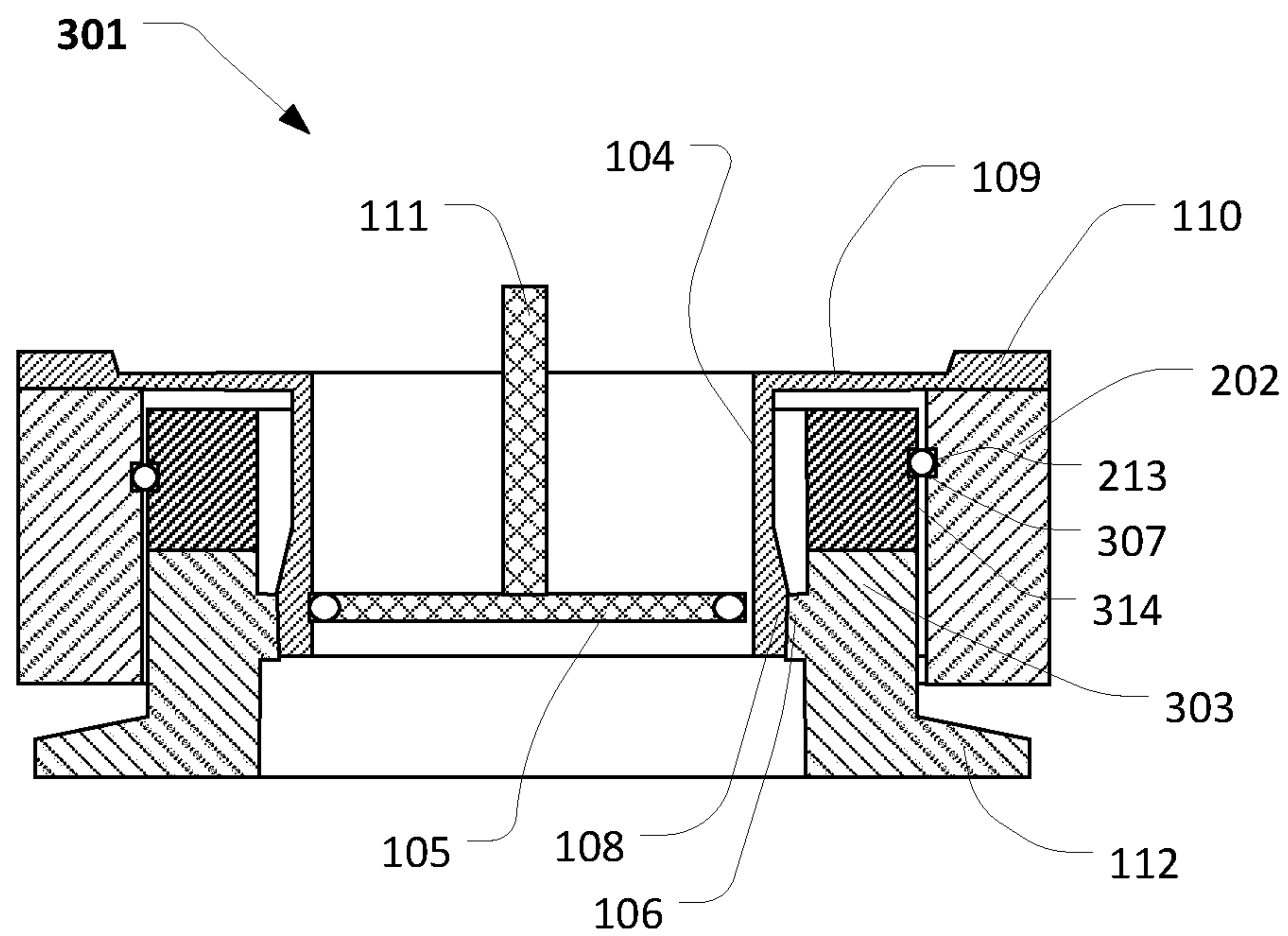


FIG. 3

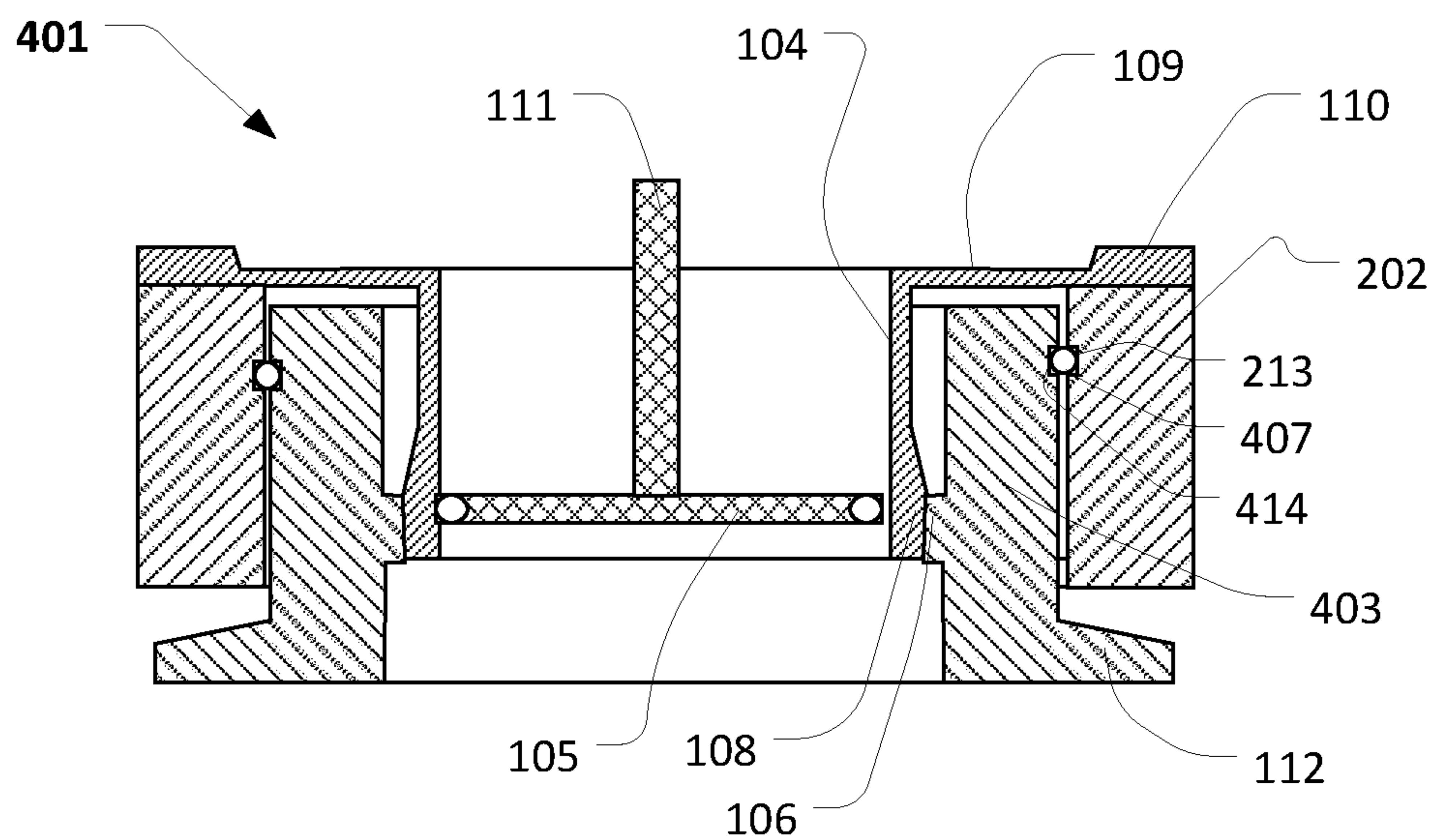


FIG. 4

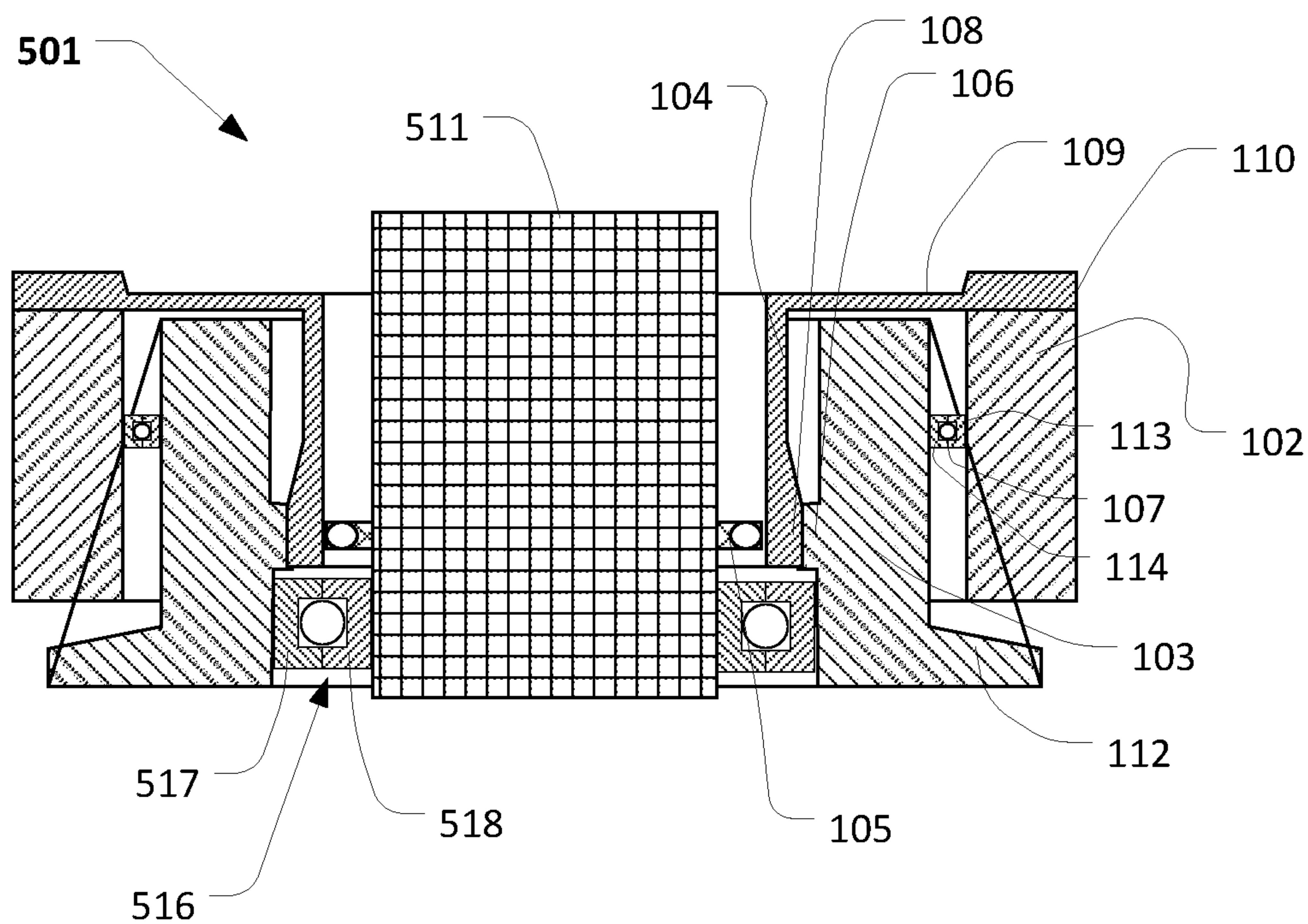


FIG. 5

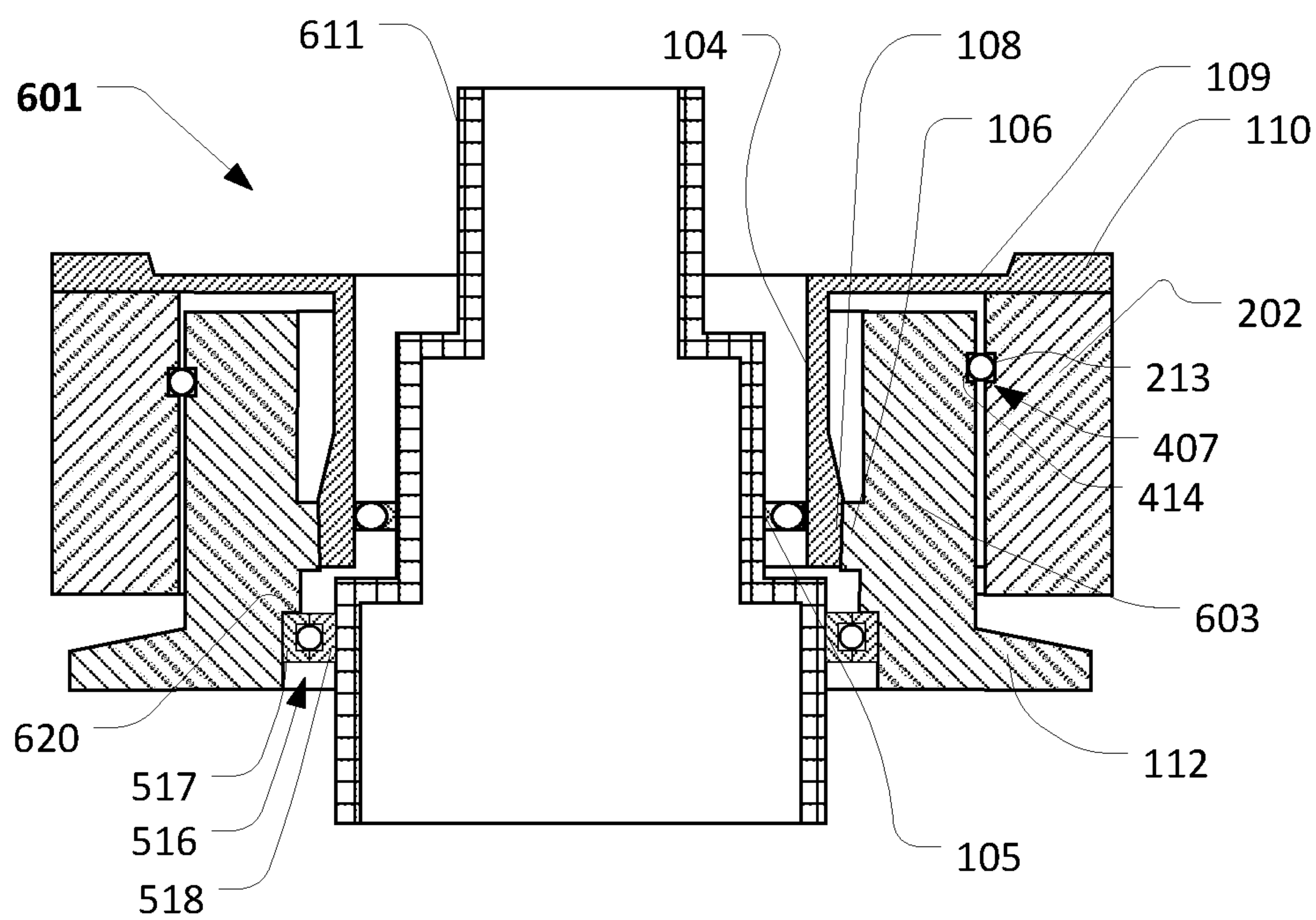


FIG. 6

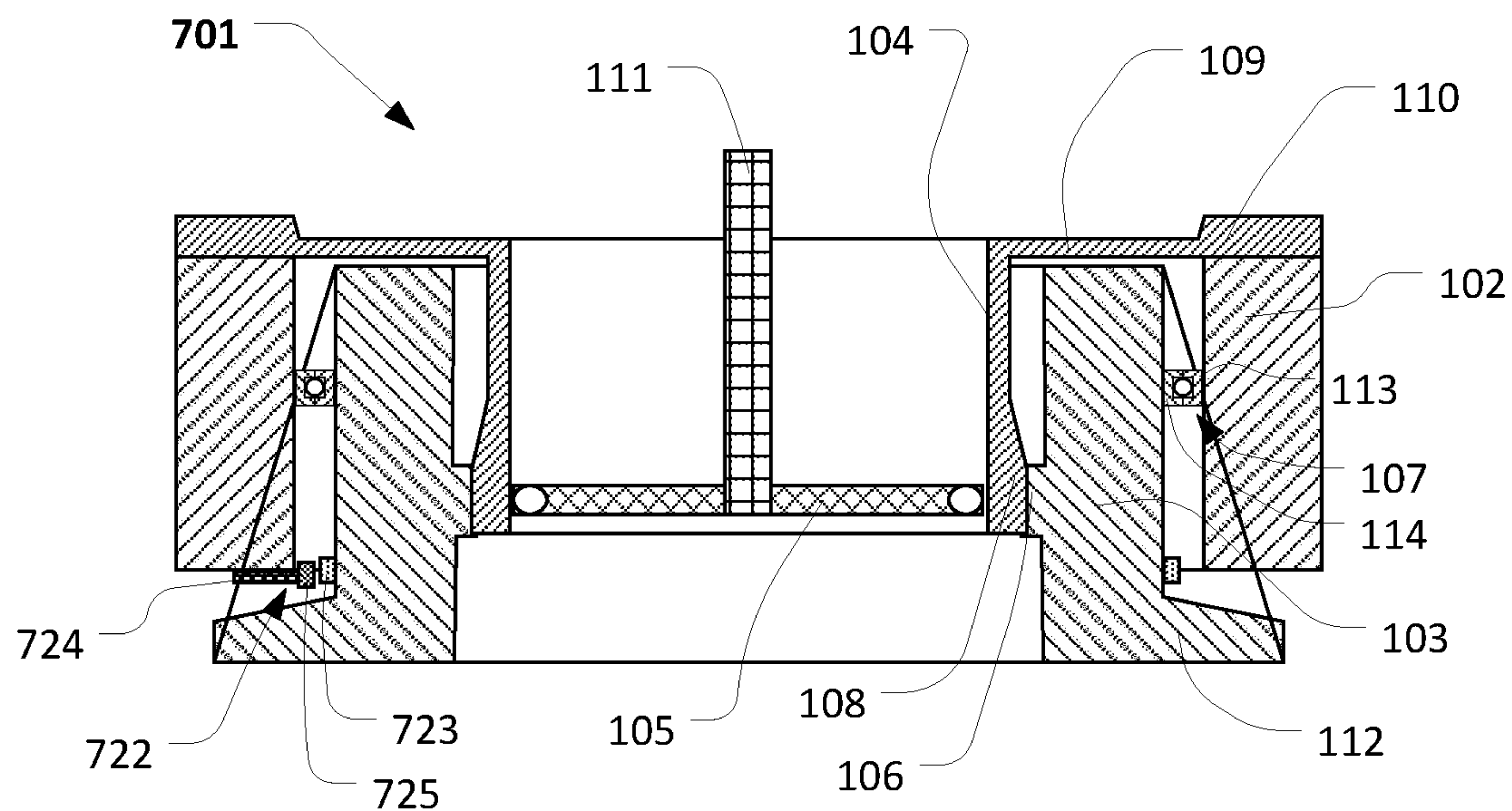


FIG. 7

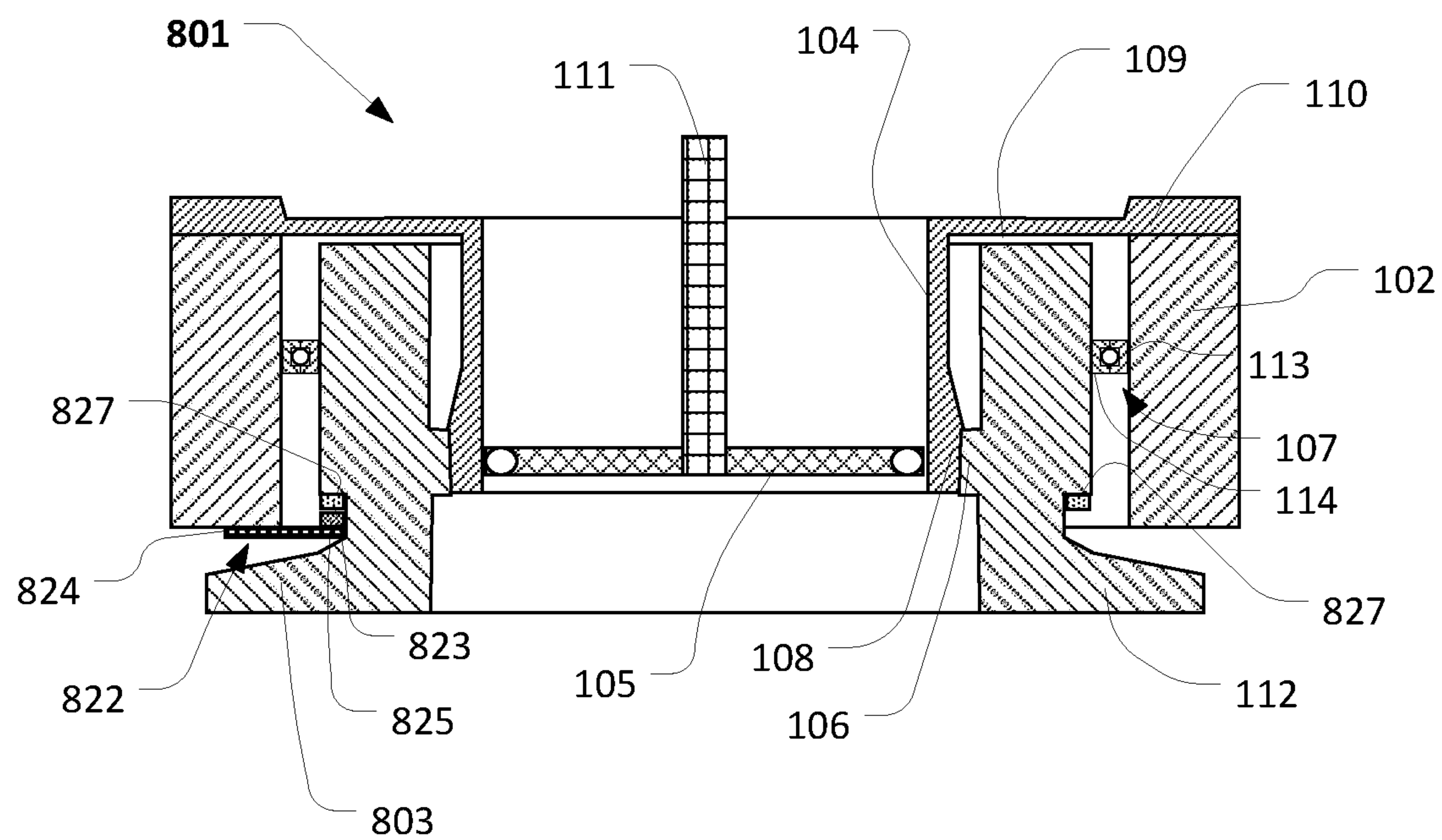


FIG. 8

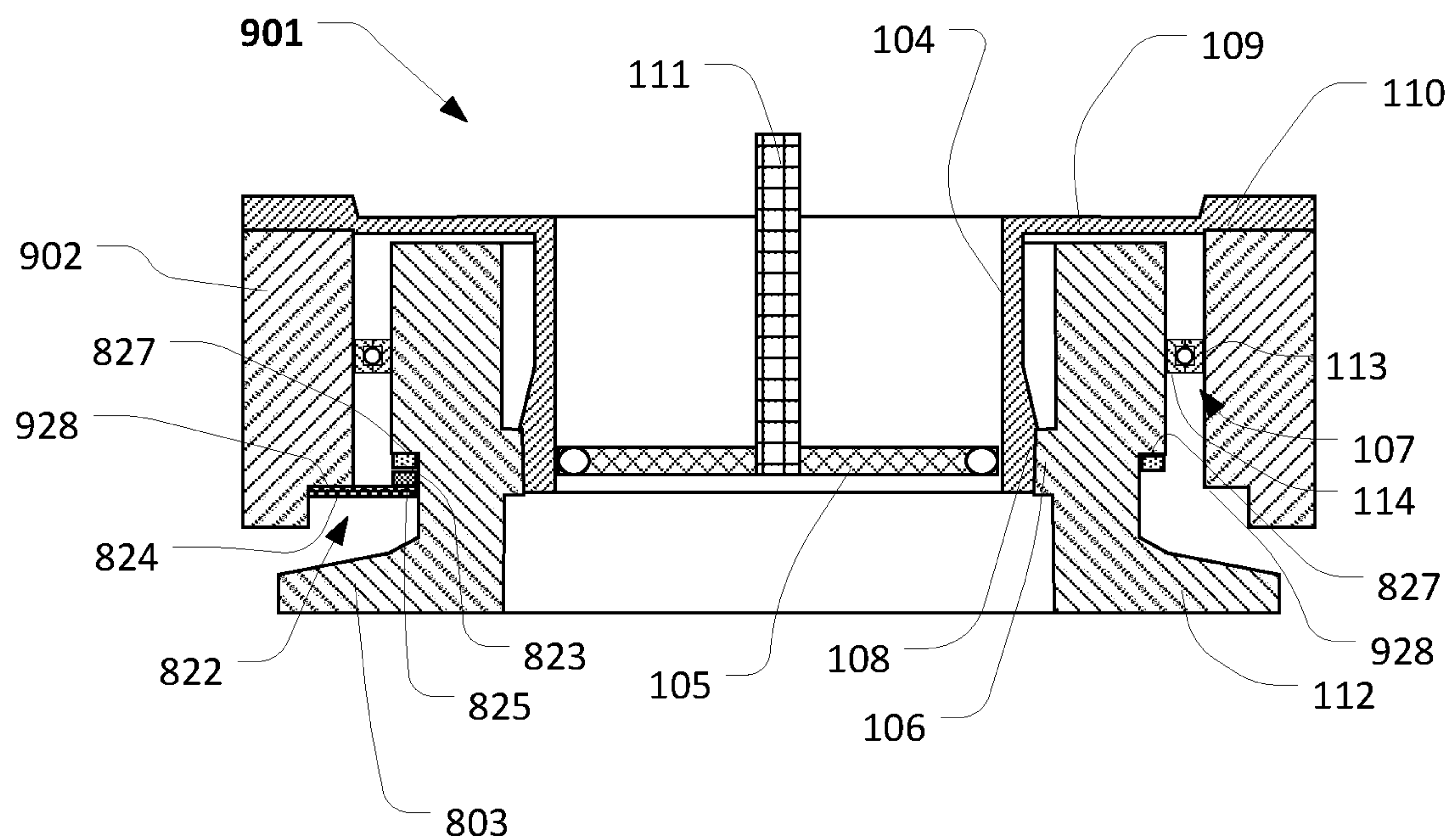


FIG. 9

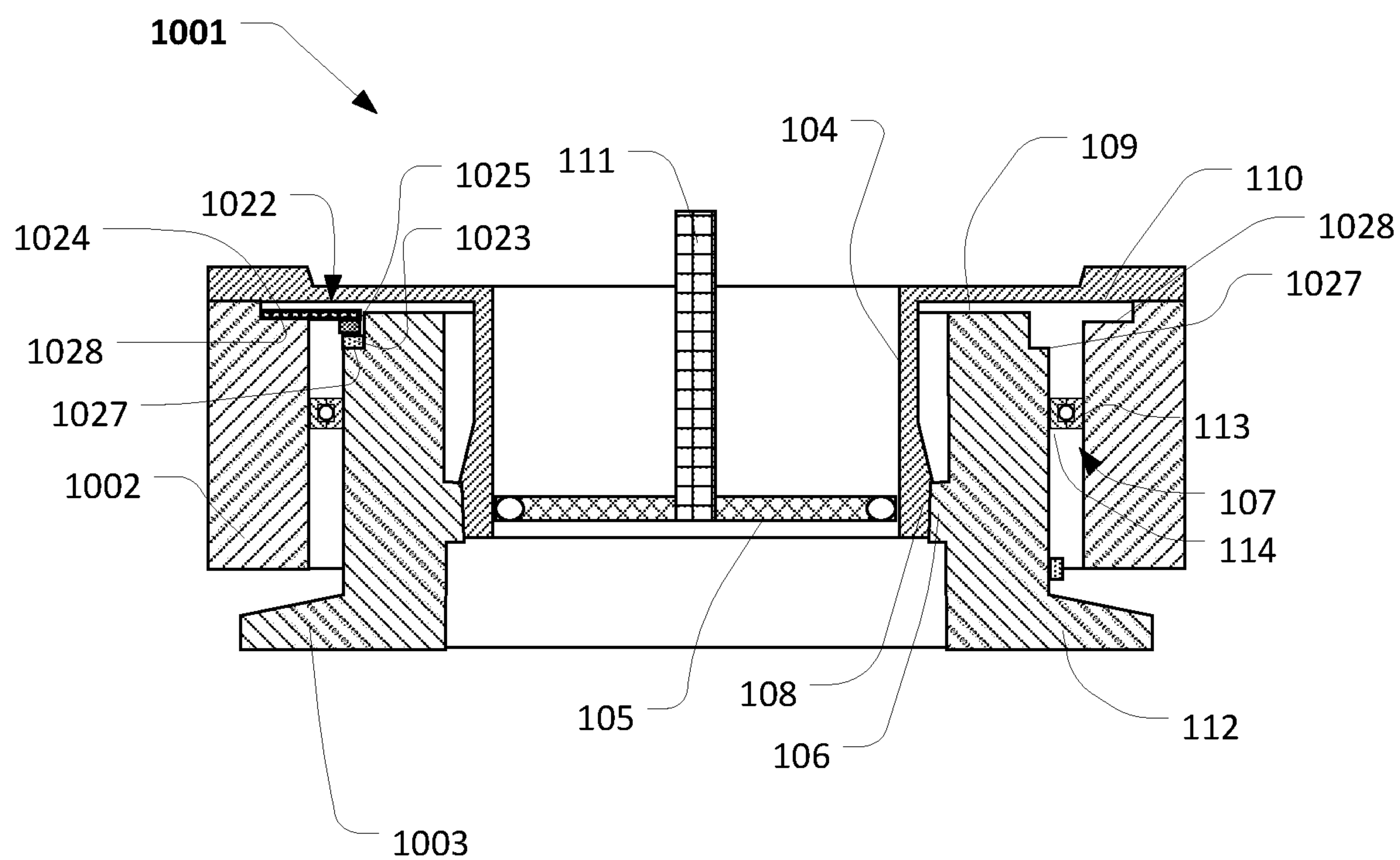


FIG. 10

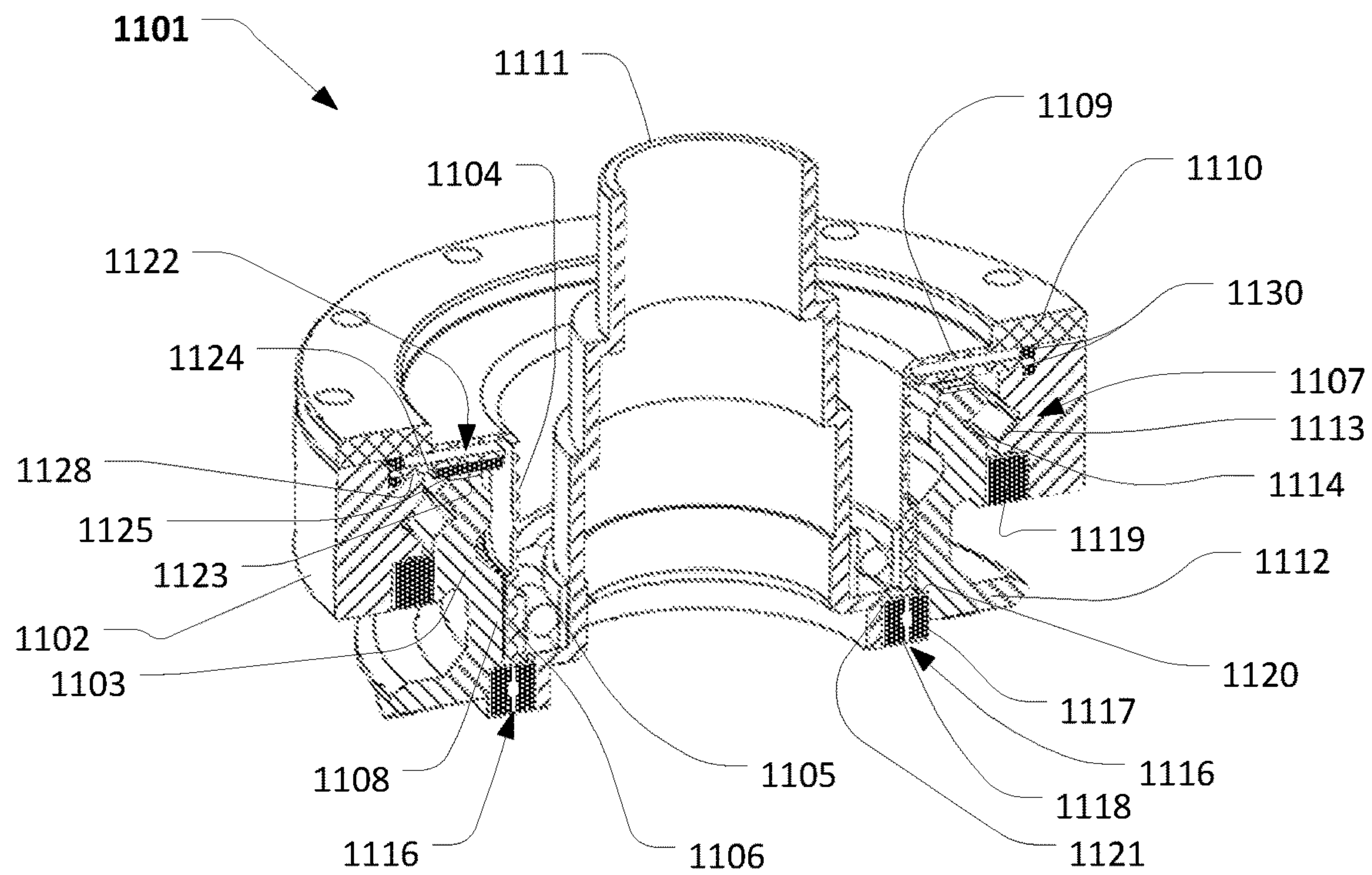


FIG. 11A

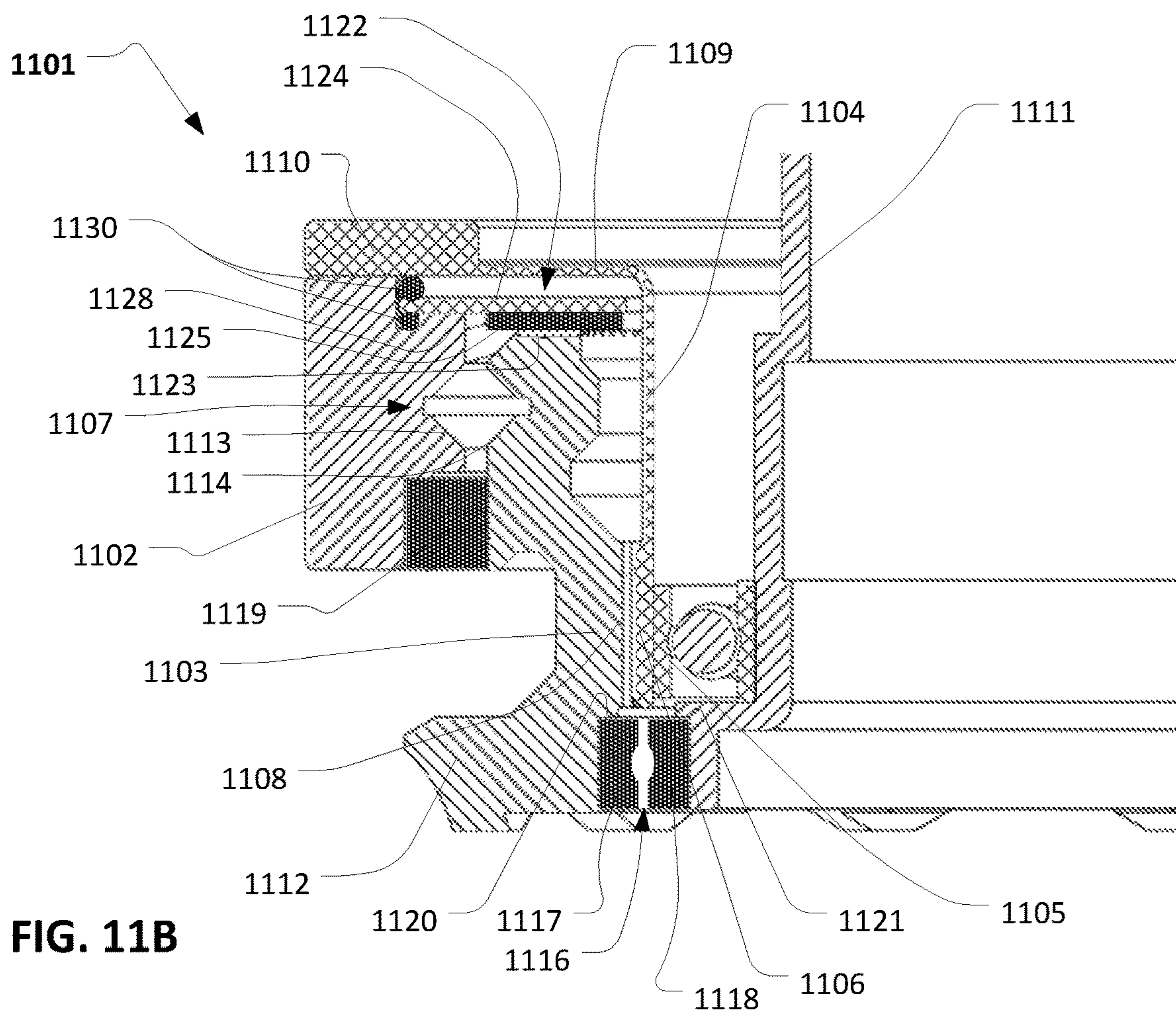


FIG. 11B

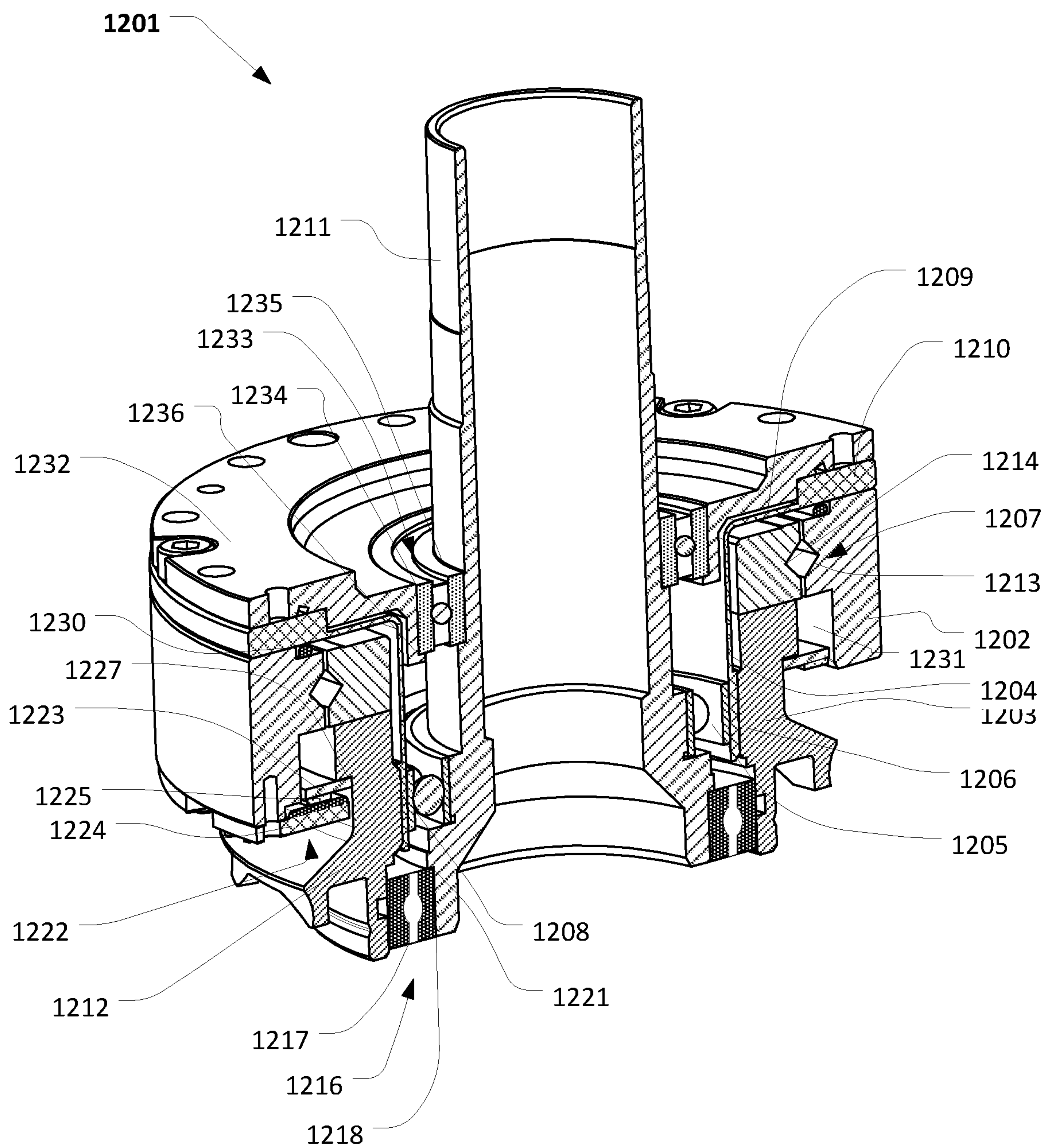


FIG. 12A

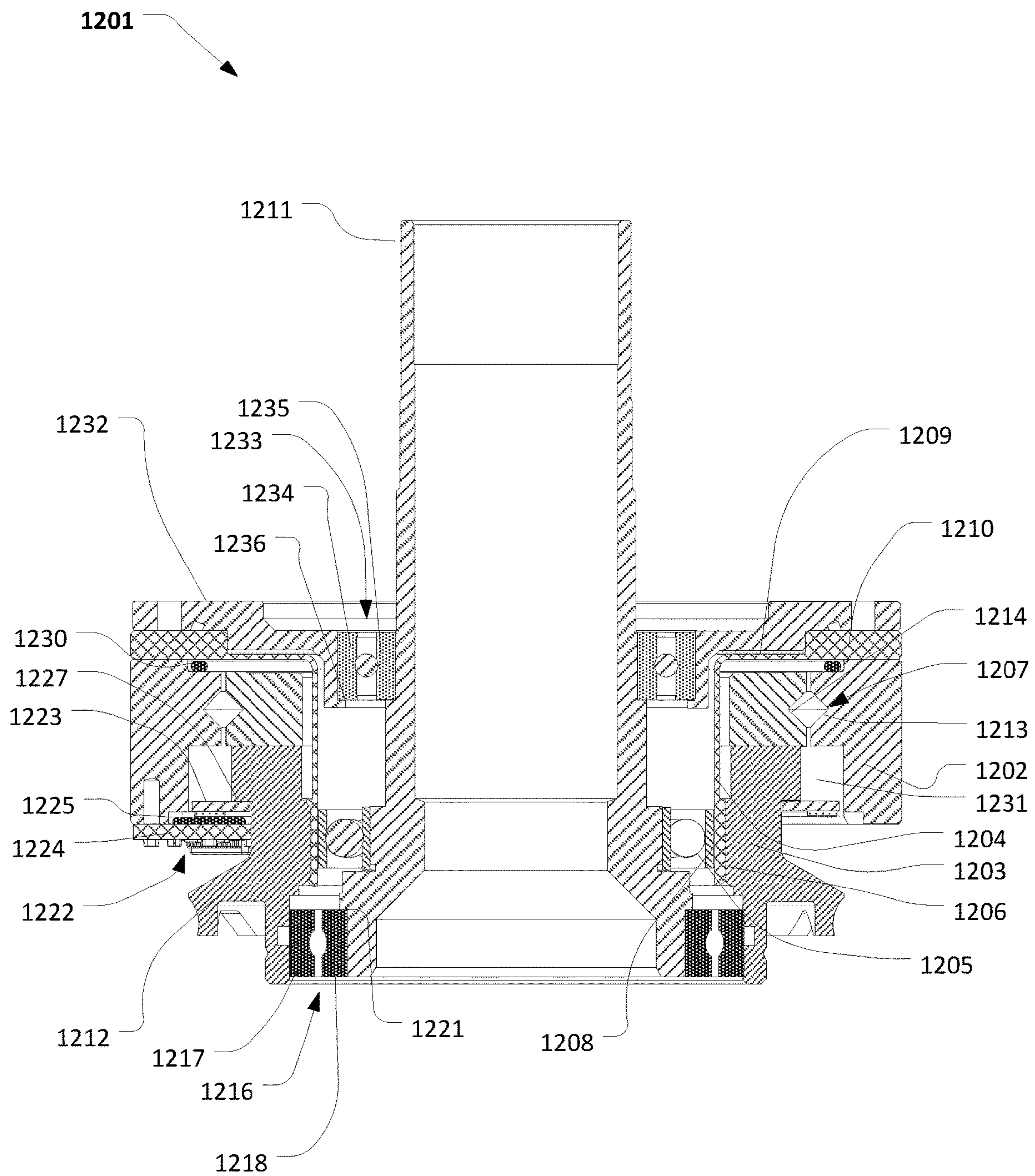


FIG. 12B

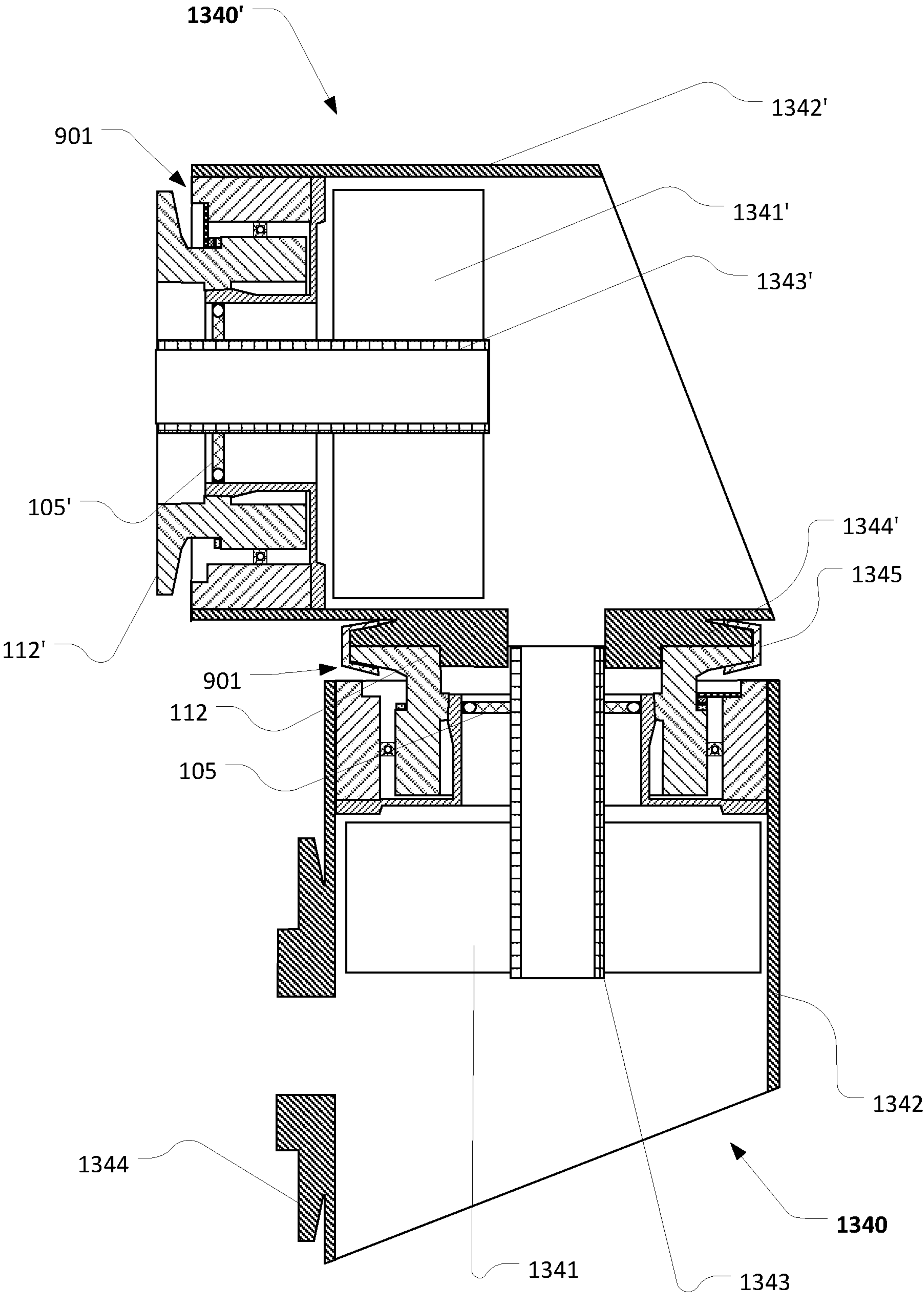


FIG. 13

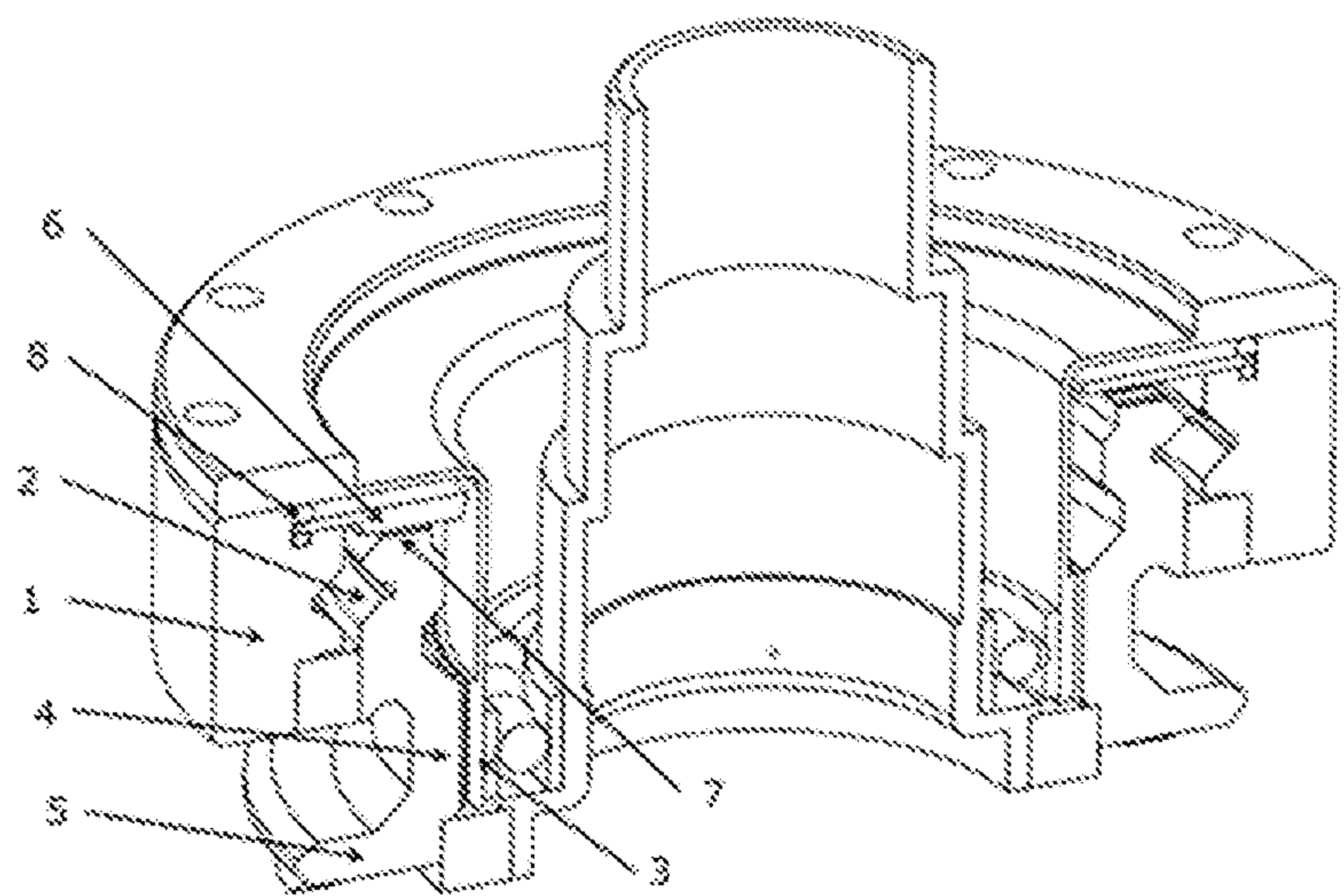


FIG. 14A

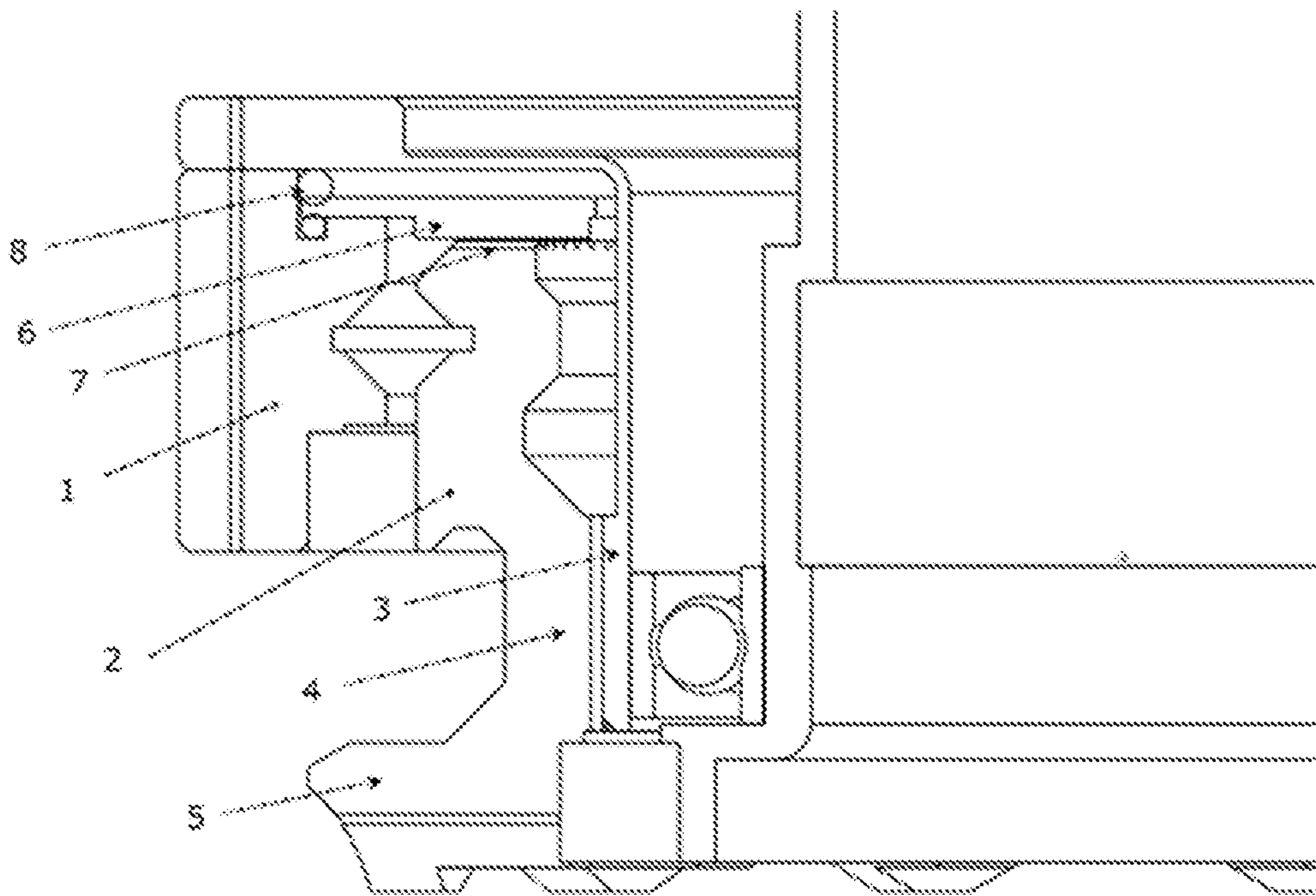


FIG. 14B

STRAIN WAVE GEAR WITH OUTPUT FLANGE AND INTEGRATED ENCODER

This application is a continuation of U.S. patent application Ser. No. 16/759,461 which was filed on Apr. 27, 2020 and which is to issue as U.S. Pat. No. 11,964,389 on Apr. 23, 2024. U.S. patent application Ser. No. 16/759,461 is a U.S. national stage entry of PCT application no. PCT/EP2018/081413 which was filed on Nov. 15, 2018. PCT application no. PCT/EP2018/081413 claims priority to European application no. 17201940.8 which was filed on Nov. 15, 2017. This application claims priority to U.S. patent application Ser. No. 16/759,461, to PCT application no. PCT/EP2018/081413, and to European application no. 17201940.8. U.S. patent application Ser. No. 16/759,461, PCT application no. PCT/EP2018/081413, and European application no. 17201940.8 are incorporated into this this application by reference.

FIELD OF THE INVENTION

The present invention relates to a strain wave gear for a robot joint. The strain wave gear comprises an outer ring and an inner ring rotatably arranged in the outer ring, where the inner ring comprises an internally toothed gear and a flex spline is arranged in the inner ring and comprise a flexible part comprising an external toothed gear. A wave generator is configured to flex the flexible part in a radial direction to partly mesh the external toothed gear with the internally toothed gear causing rotation of the inner ring in relation to the outer ring. The strain wave gear can be made cost effective, has fewer parts, easier to assemble, compact and small and has a high rigidity. Moreover, the invention relates to a strain wave gear with an encoder placed inside the gear to read the gear's output position. The present invention also relates to a robot joint where a robot motor is configured to rotate an output flange via such strain wave gear.

BACKGROUND OF THE INVENTION

In the field of robotics, where a robot arm comprises a number of robot joints connecting different parts of the robot arm and where a joint motor is configured to move the parts in relation to each other, it is known to use strain wave gears as a transmission system between the joint motor and the movable part, as the strain wave gears transmits large forces without backlash.

The prior art discloses wave gear drives with flexible external gears. Typically, such a flexible external gear comprises a flex spline, a circular diaphragm extending outward or inward in a radial direction from one open end of the body (often referred to as silk hat or cup type), a circular boss formed integrally on a circumferential outer peripheral edge of the diaphragm, and external teeth formed on a circumferential outer surface of the other open end portion of the body. Sometimes strain wave gears are designed with the flexible gear part as a cylindrical ring with external teeth (this type often referred to as ring type gears).

Strain wave gears are used in a variety of applications such as CNC-machines, robotics, satellites, solar tracking, etc. They are very precise with little or no backlash, and therefore often preferred in applications where high precision and accuracy of the output is needed. In these applications a feedback system is often used such as an electronic encoder connected to control electronics that run an electric motor driving the input side of the strain wave gear.

This setup renders it possible to control the output of the gear with high precision and accuracy. Normally a reading track for the encoder is placed somewhere on the output part of the strain wave gear being on a flat end surface or on the outside diameter of an output axle. The encoder read head is normally placed on some external gear geometry or in a housing/cabinet holding the strain wave gear. This approach normally requires adjustment to have the encoder read head positioned properly with respect to the read track. The encoder technology can be magnetic, optical, inductive or other. Another often used approach is to make a platform/bearing setup for the encoder with a flexible mechanism/axle from the strain wave gears output side to the reading track of the encoder. In this way the positioning of the encoder read head against the encoder read track can be controlled by a separate bearing held in place by a platform. This approach requires many extra parts which adds cost, requires space and has the potential to fail if quality or tolerances on the parts gets out of control.

The strain wave gears are normally built and assembled from a number of separate parts. That is the output bearing part is put together with a separate circular spline part and again with a separate output flange part. This approach makes it possible to adapt the parts to different applications by combining different output bearings and different output flanges with the circular spline. Sometimes it has been seen that the output bearing part has been machined as a combined part with the circular spline part. The downside of using separate components is that the assembly of these separate components requires high accuracy in the parts interfaces and a high number of strong screws to support the usually heavy loads on the strain wave gear assemblies.

U.S. Pat. No. 5,906,142 discloses a wave gear drive having first and second end plates arranged to rotate relative with each other by means of a cross roller bearing positioned between the plates. An inner race of the cross roller bearing is formed integrally on a circumferential inner surface with an internal gear. The inner race is directly fastened to the first end plate, while an outer race of the cross roller bearing is fastened to the second end plate in a manner such that a circular boss of a flexible external gear is held between the outer race and the second end plate. The internal teeth are positioned approximately at a radially inner side of a race-way of the cross roller bearing. Thus, the wave gear drive (1) is small and compact, and the rigidity is increased.

U.S. Pat. No. 5,775,178 discloses a wave gear device has a circular spline, a flexspline arranged within the circular spline, and a wave generator disposed within the flexspline for deflecting the flexspline in radial direction for partially engaging external tooth formed on the flexspline with internal gear teeth formed on the circular spline and shifting an engaging position in circumferential direction to cause relative rotation depending upon difference in number of teeth of the internal gear teeth and the external gear teeth between the circular spline and the flexspline. The circular spline has an annular rigid teeth portion formed with the internal gear teeth along the inner periphery thereof, a fastening portion to be rigidly secured on one of a device housing and a supporting member rotatably supported in the device housing, and a connecting portion connecting the rigid teeth portion and the fastening portion. The connecting portion has a low rigidity at least in one of a direction of an axis of the device and a direction perpendicular to the axis, in comparison with that of the rigid teeth portion.

U.S. Pat. No. 8,991,282 discloses a wave gear unit having an input shaft positioned along a center axis by first and second input bearings. A first unit end plate at the first-

input-bearing side is a composite member in which a bearing housing member of an iron-based material is integrated with an end plate main body member of a lightweight material. A second unit end plate at the second-input-bearing side is integrated with a rigid internally toothed gear, and is a composite member in which a second member of a lightweight material is integrated with a first member of a lightweight material. The first member has an end plate main body portion of the second unit end plate and a gear main body portion of the rigid internally toothed gear, while the second member has a bearing housing portion of the second unit end plate and a teeth formation portion of the rigid internally toothed gear.

SUMMARY OF THE INVENTION

The object of the present invention is to address the above described limitations with the prior art or other problems of prior art strain wave gears used for robot arms, for instance by providing a strain wave gear that is more cost effective, can be built with fewer parts and can cope with higher loads on the output and has with enhanced rigidity. Also, it is an object of the present invention to provide a strain wave gear having a more precise encoder than in prior art solutions and which does not require manual adjustment to the distance between read head and read track in radial or axial direction. This is achieved by a strain wave gear as defined by the independent claims. The dependent claims describe possible embodiments of the strain wave gear. The advantages and benefits of the present invention are described in the detailed description of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a simplified cross-sectional view of an embodiment of a strain wave gear according to a first aspect of the present invention;

FIGS. 2-6 illustrate simplified cross-sectional views of various embodiments of a strain wave gear according to the first aspect of the present invention;

FIG. 7 illustrates a simplified cross-sectional view of an embodiment of a strain wave gear according to a second aspect of the present invention;

FIGS. 8-10 illustrate simplified cross-sectional views of various embodiments of a strain wave gear according to the second aspect of the present invention;

FIGS. 11A and 11B illustrate a strain wave gear according to the present invention;

FIGS. 12A and 12B illustrate a strain wave gear according to the present invention;

FIG. 13 illustrates a robot joint comprising a strain wave gear according to the present invention;

FIGS. 14A and 14B illustrate an alternative example of a wave gear drive according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is described in view of exemplary embodiments only intended to illustrate the principles of the present invention. The skilled person will be able to provide several embodiments within the scope of the claims. Throughout the description, the reference numbers of similar elements providing similar effects have the same last two digits. Further it is to be understood that in the case that an

embodiment comprises a plurality of the same features then only some of the features may be labeled by a reference number.

FIG. 1 illustrates a simplified cross-sectional view of a strain wave gear 101 according to a first aspect of the present invention. The strain wave gear comprises an outer ring 102, an inner ring 103, a flex spline 104 and a wave generator 105.

The outer ring 102 is formed as an annular shaped body and the inner ring 103 is rotatable arranged in the central opening of the outer ring. In the illustrated embodiment the outer ring is provided as a cylinder, however it is noticed that the outer ring does not need to be formed as a geometrical cylinder or annulus, if the inner ring 103 can be rotatable arrange in the central opening of the outer ring. Consequently, the outer ring may have many different forms. The outer ring serves as the housing of the strain wave gear and can for instance be used to secure the strain wave gear in relation to a motor or inside a robot joint.

The inner ring 103 is formed as an annular shaped body and the flex spline 104 is arranged in the central opening of the inner ring. In the illustrated embodiment the part of the inner ring, which is arranged in the outer ring, is formed as a cylinder. However, it is noticed that the inner ring does not need to be formed as a geometrical cylinder or annulus, if the inner ring 103 can be rotatable arrange in the central opening of the outer ring. Consequently, the inner ring may have many different forms. The inner ring 103 comprises also an internally toothed gear 106 arranged at the inner wall of the inner ring and facing the central opening of the inner ring. In the illustrated embodiment the inner ring is rotatable arranged in the outer ring via an internal bearing 107.

The internal bearing is illustrated as a ball bearing comprising an outer racer 113 arranged in the outer ring 102 and an inner racer 114 wherein the inner ring 103 is arranged. However, it is to be understood that any kind of bearing can be used, for instance ball bearings, cross roller bearings, needle bearings, sliding bearings etc. or any other mechanism allowing the inner ring to rotate in relation to the outer ring. It is also noted the more than one internal bearing may be provided.

The flex spline 104 is formed as a flexible cylindrical body, arranged in the inner ring and comprises an external toothed gear 108. The external toothed gear is configured to at least partially intermesh with the internal toothed gear 106. The flex spline comprises an annular diaphragm 109 formed integrally with the cylindrical body and extending outwardly in relation to the cylindrical body. The annular diaphragm 109 comprises an annular boss 110 formed integrally on a circumferential outer peripheral edge of the diaphragm. The annular boss 110 is fixed to the outer ring 102 using any kind of fasteners such as screws, rivets, nails, click/snap mechanisms, adhesive, welding or any other kind of means for fastening the annular boss to the outer ring. Consequently, the inner ring is arranged between the outer ring 102 and the cylindrical body of the flex spline 104. The external gear teeth 108 are formed at the other end of the cylindrical body and extend along the outer peripheral surface.

The wave generator 105 is rotatably arranged in the flex spline 104 and rotatable by an input shaft 111. The input shaft is configured to rotate the wave generator in relation to the flex spline and the wave generator is upon rotation configured to flex the flexible cylindrical body in a radial direction to partly mesh the external toothed gear 108 with the internally toothed gear 106. The wave generator can for instance be provided as an elliptical rigid cam, as a elliptical

5

wave bearing or any other mechanism configured to flex parts of the cylindrical body in a radial direction. The number of teeth of the internal toothed gear and the external toothed gear are different and rotation of the wave generator moves meshing positions of the gears in a circumferential direction causing the inner ring to rotate in relation to the outer ring. The input shaft can for instance be driven by a motor whereby the strain wave gear forms a transmission system between the motor and output side of the strain wave gear.

A part of the inner ring extends out of said outer ring and comprises an outwardly protruding output flange **112**. The outwardly protruding output flange extends outwardly in relation to the inner ring and towards the outer ring. Providing the inner ring with an outwardly protruding output flange makes it possible to connect the strain wave gear directly to the object to be driven by the strain wave gear. This is beneficial in the field of robotics where strain wave gears often are used to drive parts of a robot arm; thus, the strain wave gear according to the first aspect of the present invention can be connected directly with a robot link or a robot joint. The outwardly protruding output flange makes it possible to increase the diameter of the contact surface whereby a better and more reliable and stable contact can be obtained between the strain wave gear and the object to be driven by the strain wave gear. Further the outwardly protruding output flange can be provided with mechanical elements ensuring a better connection between the strain wave gear and the connected object, such as connecting teeth, connecting flanges, indicating elements (e.g. matching surface structures) ensuring correct orientation of the connected object in relation to the strain wave gear. For instance, in one embodiment the outwardly protruding output flange can be provided as one of the component flanges of the releasable joint assembly disclosed by WO 2018/130447 incorporated herein by reference.

The geometry/shape of the outwardly protruding output flange can be very precisely centered with respect to the gear axis as it is integrated with the inner ring comprising the internally toothed gear, and there are thus no assembly tolerances from separate parts being screwed together. The gear will be easier and quicker to assemble because no screws are needed to assemble the separate parts. The quality and reliability of the gears will be higher because there is no risk of screws breaking or becoming loose and there is no risk of flanges slipping if screws are not tightened correctly. Further, a more rigid strain wave gear is hereby provided as the rotating toothed gear of the inner ring and outwardly protruding output flange can be provided as one single body which ensures a more direct transfer of torque from the toothed gear to the output flange. Consequently, more rigid connection can be established between different part of a robot arm.

Furthermore, the weight of the strain wave gear will be lower because the integration of parts can be optimized for strength, where the separate parts need excessive material to form support geometry and centering rims, and because no screws are needed. The cost of the strain wave gear will be lower because of fewer parts to be fabricated and less material used. The strain wave gear will be able to drive higher loads on the outwardly protruding output flange as the outwardly protruding output flange can be provided as an integral part of the inner ring. The strain wave gear according to the first aspect of the invention thus provide a strain wave gear that is more cost effective, can be built with fewer parts and can cope with higher loads on the output and has enhanced rigidity.

6

FIG. 2 illustrates a simplified cross-sectional view of another embodiment of a strain wave gear **201** according to a first aspect of the present invention. The strain wave gear **201** is like the strain wave gear **101** illustrated in FIG. 1 and similar elements have been given the same reference numbers as in FIG. 1 and will not be described further. In this embodiment at least a part of the outer racer **213** of the internal bearing **207** is integrally formed in the outer ring **202** and the inner racer **214** of the internal bearing is provided as a separate part wherein the inner ring **103** is arranged. The outer racer can for instance be provided as a recess in the outer ring where the recess is configured to guide the rotational elements of the internal bearing. This makes it possible to arrange the inner ring and outer ring closer to each other whereby a more compact strain wave gear can be provided.

FIG. 3 illustrates a simplified cross-sectional view of another embodiment of a strain wave gear **301** according to a first aspect of the present invention. The strain wave gear **301** is like the strain wave gears **101** and **201** illustrated in FIGS. 1-2 and similar elements have been given the same reference numbers and will not be further described. In this embodiment the inner racer **314** of the internal bearing **307** is provided as a separate part and one end of the inner ring **303** is coaxially connected to the inner racer. The inner ring **303** and inner racer **314** are thus consecutively arranged along the axis of rotation of the inner ring. The inner ring **303** and the inner racer **314** can be connected using any kind of fasteners such as screws, rivets, nails, click/snap mechanisms, adhesive, welding, press fit or any other kind of means for fixing the inner ring **303** and the inner racer **314** in relation to each other. This makes it possible to provide the inner ring and the inner racer seaming as one body/part where the inner racer and the inner ring can be made of different materials. This makes it possible to reduce the radial dimensions of the inner ring and the inner racer as the outer surface of the inner ring and the inner racer can be aligned. Consequently, the inner ring and outer ring can be arranged very close to each other whereby a more compact strain wave gear can be provided. In this embodiment the internally toothed gear **106** and the outwardly protruding flange **112** of the inner ring **303** is fabricated as a single part. This leads to the fact that the output side of the strain wave gear is more rigid as the toothed gear and outwardly protruding output flange is provided as a single body. The forces causing the rotation of the inner ring is applied by the flex spline directly to the internally toothed gear of the inner ring can thus be directly transferred to the outwardly protruding output flange.

FIG. 4 illustrates a simplified cross-sectional view of another embodiment of a strain wave gear **401** according to a first aspect of the present invention. The strain wave gear **401** is like the strain wave gears **101** and **201** illustrated in FIGS. 1-2 and similar elements have been given the same reference numbers and will not be further described. In this embodiment at least, a part of the outer racer **213** of the internal bearing **407** is integrally formed in the outer ring **202** and the inner racer **414** of the internal bearing is integrally formed in the inner ring **403**. This makes it possible to arrange the inner ring and outer ring very close to each other whereby a more compact strain wave gear can be provided. Further this makes it possible to reduce the number of elements that need to be assembled as the outer racer **213** and the inner racer **414** of the internal bearing **407** respectively are provided as integral parts of the outer ring **202** and inner ring **403**. In other words, the outer ring forms the outer racer of an internal bearing of a strain wave gear

and the inner ring forms the inner racer of an internal bearing of a strain wave gear. The inner racer of the internal bearing, the internally toothed gear and the outwardly protruding output flange are thus fabricated as a single part.

FIG. 5 illustrates a simplified cross-sectional view of another embodiment of a strain wave gear **501** according to the first aspect of the present invention. The strain wave gear **501** is like the strain wave gear **101** illustrated in FIG. 1 and similar elements have been given the same reference numbers as in FIG. 1 and will not be described further. In this embodiment the input shaft **511** extends through the flex spline **104** and is rotatably supported by the inner ring **103** via at least one input shaft support bearing **516**. The input shaft support bearing **516** comprises an outer racer **517** arranged in the inner ring **103** and inner racer **518** wherein the input shaft **511** is arranged. The input shaft **511** is illustrated as a solid input shaft, however it is to be understood that the input shaft also can be provided as a hollow input shaft for instance to reduce the weight of the strain wave gear or to allow wires to be lead through the strain wave gear.

FIG. 6 illustrates a simplified cross-sectional view of another embodiment of a strain wave gear **601** according to the first aspect of the present invention. The strain wave gear **601** is like the strain wave gears illustrated in FIGS. 1-5 and similar elements have been given the same reference numbers and will not be further described. The input shaft **611** is provided as a hollow input shaft and the inner ring **603** comprise an inner annular flange **620** configured to support the input shaft support bearing **516**. This ensures that the input shaft **611** is arranged at the correct positions inside the strain wave gear. Further the inner annular flange assists during assembly of the strain wave gear as it can be used as a guide to ensure correct placement of the input shaft support bearing. Similar it is noted that the input shaft **611** can comprise an outer annular flange (not shown) configured to support the input shaft support bearing **516**.

It is noted that the various embodiments of the internal bearing **107**, **207**, **307**, **407** illustrated and described in connection with FIGS. 1-4 also can be combined with the embodiments comprising a support bearing supporting the input shaft as illustrated in FIGS. 5-6.

FIG. 7 illustrates a simplified cross-sectional view of a strain wave gear **701** according to a second aspect of the present invention. The strain wave gear **701** is like the strain wave gear **101** illustrated in FIG. 1 and similar elements have been given the same reference numbers as in FIG. 1 and will not be described further. In this embodiment an encoder reader **722** is disposed on the outer ring **102** and an encoder track **723** is disposed on the inner ring **103**. This makes use of the already very precise inner ring **103** and outer ring **102** of the strain wave gear to position the encoder parts. By placing the encoder reader **722** on the fixed outer ring **102** and placing the encoder track **723** on the rotating inner ring **103**, there is no need for extra parts, and the tolerance chain between the encoder reader and encoder track is the shortest possible. E.g. magnetic encoders are relying on short reading distance to deliver high accuracy and precision, and this will be possible with this invention without the need for additional manual adjustment after assembly.

The encoder reader **722** and the encoder track **723** can be mounted directly on the inner ring and outer ring parts without need for special platforms/brackets or other support parts. This saves weight and cost. The reading distance between the encoder reader and the encoder track will be very precise without the need for manual adjustment. This is

an advantage because of easier assembly and lower cost. The precision and accuracy of the encoder readout can be higher than in other designs because of the precisely controlled reading distance between encoder parts. This is a big advantage in many applications, such as robotics, where precision and accuracy are needed. There is no need for mechanical transmission parts to drive the encoder track relatively to the output from the gear, which would result in lower precision and accuracy plus added cost and quality issues. The encoder parts are mechanically well protected by sitting inside the gear. This is an advantage in applications with harsh environments that could damage the delicate electronics. The encoder track **723** can be of large diameter which raises precision and accuracy.

The encoder reader comprises an encoder PCB (printed circuit board) **724** comprising electronics for controlling and reading signals to and from an encoder head **725**. The encoder track **723** comprises a plurality of indicators which can be read by the encoder head whereby the encoder reader can obtain to position of the inner ring in relation to the outer ring. For instance, the encoder head may be a magnetic head (such as hall sensors) capable reading a magnetic encoder track, an optical sensor capable of reading an optical track. In the illustrated embodiment the encoder PCB **724** is arranged at the end of the outer ring opposite the end where the annular boss **110** is fixed to the outer ring **102**. The encoder head **725** is arranged on the encoder PCB and faces the outer surface of the inner ring. The encoder tracks **723** is arranged at the outer surface of the inner ring at a position facing the encoder head **725**.

FIG. 8 illustrates a simplified cross-sectional view of another embodiment of a strain wave gear **801** according to the second aspect of the present invention. The strain wave gear **801** is like the strain wave gear **701** illustrated in FIG. 7 and similar elements have been given the same reference numbers as in FIG. 1 and will not be described further. The encoder reader **822**, the encoder PCB **824**, the encoder head **825**, the encoder track **823** functions like the encoder reader **722**, the encoder PCB **724**, the encoder head **725**, the encoder track **723** describe previously and their functionality will not be described further.

In this embodiment the encoder PCB **824** is arranged at the end of the outer ring **102** opposite the end where the annular boss **110** is fixed to the outer ring **102**. The encoder track **824** is provided as an annulus and is arranged on an outer annular flange **827** of the inner ring **802**. The outer annular flange **827** of the inner ring comprises a surface facing away from the end of the strain wave gear where the annular boss **110** is attached to the outer ring **802**. The encoder head **825** is arranged on the encoder PCB **824** and faces the surface facing of the outer annular flange facing away from the end of the strain wave gear the annular boss **110** is attached to the outer ring. Consequently, the encoder head faces the annular encoder track **823** and can read the indication of the annular encoder track. This makes it possible to use standard encoders which typically comprises an annular encoder track.

FIG. 9 illustrates a simplified cross-sectional view of another embodiment of a strain wave gear **901** according to the second aspect of the present invention. The strain wave gear **901** is like the strain wave gear **701** and **801** illustrated in FIGS. 7 and 8 and similar elements have been given the same reference numbers and will not be described further.

In this embodiment the encoder reader **822** is disposed on an inner annular flange **928** of the outer ring **902**. The inner annular flange **928** of the outer ring comprises a surface facing away from the end where the annular boss **110** is

attached to the outer ring **902**; and the encoder PCB **824** is arranged at the surface of the inner annular flange **928** facing away from the end where the annular boss **110** is attached to the outer ring **802**.

FIG. **10** illustrates a simplified cross-sectional view of another embodiment of a strain wave gear **1001** according to the second aspect of the present invention. The strain wave gear **1001** is like the strain wave gear **701** illustrated in FIG. **7** and similar elements have been given the same reference numbers as in FIG. **7** and will not be described further. The encoder reader **1022**, the encoder PCB **1024**, the encoder head **1025**, the encoder track **1023** functions like the encoder reader **722**, the encoder PCB **724**, the encoder head **725**, the encoder track **723** describe previously and their functionality will not be described further.

In this embodiment the encoder reader **1022** is disposed on an inner annular flange **1028** of the outer ring **1002**. The inner annular flange **1028** of the outer ring comprises a surface facing towards the end where the annular boss **110** is attached to the outer ring **1002**; and the encoder PCB **1024** is arranged at the surface of the inner annular flange **1028** facing towards the end where the annular boss **110** is attached to the outer ring **802**. The encoder track **1025** is provided as an annulus and is arranged on an outer annular flange **1027** of the inner ring **1002**. The outer annular flange **1027** of the inner ring comprises a surface facing towards the end of the strain wave gear where the annular boss **110** is attached to the outer ring **1002**. The encoder head **1025** is arranged on the encoder PCB **1024** and faces the surface facing of the outer annular flange facing towards the end of the strain wave gear where the annular boss **110** is attached to the outer ring. It is noted that alternatively the annular encoder tracks **1023** can be arranged at the end surface of the inner ring that faces towards the end of the strain wave gear where the boss **110** is attached to the outer ring.

FIGS. **11A** and **11B** illustrate a strain wave gear **1101** according to the present invention, where FIG. **11A** is a perspective view of the strain wave gear with one half of the strain wave gear cut away and FIG. **11B** is a cross-sectional view of one half of the strain wave gear. The strain wave gear comprises an outer ring **1102**, an inner ring **1103**, a flex spline **1104** and a wave generator **1105**.

As described previously the outer ring **1102** and inner ring **1103** are formed as an annular shaped body. The inner ring **1103** is rotatably arranged in the central opening of the outer ring **1102** and the flex spline **1104** is arranged in the central opening of the inner ring **1102**. The inner ring **1103** comprises an internally toothed gear **1106** arranged at the inner wall of the inner ring and facing the central opening of the inner ring. The inner ring is rotatably arranged in the outer ring via an internal bearing **1107**. The internal bearing **1107** is embodied as a cross roller bearing where the outer racer **1113** is integrally formed in the outer ring **1102** and the inner racer is integrally formed in the inner ring **1103**. The flex spline **1104** is formed as a flexible cylindrical body, arranged in the inner ring and comprises an external toothed gear **1108**. The external toothed gear is configured to at least partially intermesh with the internal toothed gear **1106**. The flex spline comprises an annular diaphragm **1109** formed integrally with the cylindrical body and extending outwardly in relation to the cylindrical body. The annular diaphragm **1109** comprises an annular boss **1110** formed integrally on a circumferential outer peripheral edge of the diaphragm. The annular boss **1110** is fixed to the outer ring **1102** using any kind of fasteners such as screws, rivets, nails, click/snap mechanisms, adhesive, welding or any other kind of means for fastening the annular boss to the outer ring. Conse-

quently, the inner ring is arranged between the outer ring **1102** and the cylindrical body of the flex spline **1104**. The external gear teeth **1108** are formed at the other end of the cylindrical body and extend along the outer peripheral surface of the cylindrical body. The wave generator **1105** is rotatably arranged in the flex spline **1104** and rotatable by a hollow input shaft **1111**. The input shaft is configured to rotate the wave generator in relation to the flex spline and the wave generator is upon rotation configured to flex the flexible cylindrical body in a radial direction to partly mesh the external toothed gear **1108** with the internally toothed gear **1106**. In the illustrated embodiment the wave generator is provided as an elliptical wave generator as known in the art of strain wave gears. The number of teeth of the internal toothed gear and the external toothed gear are different and rotation of the wave generator moves meshing positions of the gears in a circumferential direction causing the inner ring to rotate in relation to the outer ring. The input shaft can for instance be driven by a motor whereby the strain wave gear forms a transmission system between the motor and output side of the strain wave gear.

A part of the inner ring extends out of said outer ring and comprises an outwardly protruding output flange **1112**. The outwardly protruding output flange extends outwardly in relation to the inner ring and towards the outer ring. Providing the inner ring with an outwardly protruding output flange makes it possible to connect the strain wave gear directly to the object to be driven by the strain wave gear, whereby the previously described advantages and benefits can be achieved. In this embodiment the outwardly protruding output flange is provided as one of the component flanges of the releasable joint assembly disclosed by WO 2018/130447 incorporated herein by reference.

The input shaft **1111** extends through the flex spline **1104** and is rotatably supported by the inner ring **1103** via an input shaft support bearing **1116**. The input shaft support bearing **1116** comprises an outer racer **1117** arranged in the inner ring **1103** and inner racer **1118** wherein the input shaft **111** is arranged. The inner ring **1103** comprises an inner annular flange **1120** configured to support the input shaft support bearing **1116**, and the input shaft **1111** can comprise an outer annular flange **1121** configured to support the input shaft support bearing **1116**. This ensures that the input shaft **1111** is arranged at the correct position inside the strain wave gear. A seal **1119** is arranged between the inner ring **1102** and the outer ring **1103** to prevent lubrication provided inside the internal bearing **1107** from leaking out. The sealing can be provided as any kind of sealing known from strain wave gears.

The strain wave gear **1101** comprises an encoder reader **1122** disposed on the outer ring **1102** and an encoder track **1123** disposed on the inner ring **1103**, where the encoder reader comprises an encoder PCB (printed circuit board) **1124** comprising electronics for controlling and reading signals to and from an encoder head **1125**. By placing the encoder reader **1122** on the fixed part of the outer ring **1102** and placing the encoder track **1123** on the rotating inner ring **1103**, there is no need for extra parts, and the tolerance chain between the encoder parts is the shortest possible. Especially magnetic encoders are relying on short reading distance to deliver high accuracy and precision, and this will be possible with this invention without the need for additional manual adjustment after assembly. In this embodiment electronic encoder parts (encoder reader **1122** and encoder track **1123**) are arranged inside a strain wave gear which is unusual because the encoder parts will be in a cavity normally filled with oil or grease. This is however not prohibitive when

11

using a suitable oil or grease and protecting the electronics properly. Gaskets **1130** can be placed on each side of the encoder PCB **1124** and one or more wires can exit through a dedicated tunnel from the gear cavity to the outside. The wires are typical needed in order to receive encoder signals from the encoder reader. This saves weight and cost. The reading distance between the encoder head **1125** and the encoder track **1123** will be very precise without the need for manual adjustment. This is an advantage because of easier assembly and lower cost. The precision and accuracy of the encoder readout can be higher than in other designs because of the precisely controlled reading distance between encoder parts. This is a big advantage in many applications where precision and accuracy are needed. There is no need for mechanical transmission parts to drive the encoder track relatively to the output from the gear. This would result in lower precision and accuracy plus added cost and quality issues. The encoder parts are mechanically well protected by sitting inside the strain wave gear. This is an advantage in applications with harsh environments that could damage the delicate electronics. The encoder track **1123** can be of large diameter which raises precision and accuracy.

In one embodiment the Encoder PCB **1124** and electronics can be coated with a suitable coating to make sure it does not release any chemical agents to the grease/oil inside the gear. The encoder reading principle can be selected specially for use where grease/oil can be present e.g. magnetic vs optical. The reading track can be a physical pattern in the surface of the output bearing material (machined, etched, laser engraved etc.) to avoid extra parts inside the gear. The wire from the encoder PCB can be a flex wire exiting from the edge of the PCB, to make it easier to place gaskets around the PCB.

In this embodiment three parts of a typical strain wave gear are assembly into a single part. This means that the inner racer **1114** of the internal bearing **1107**; the internal toothed gear **1108** (also called a circular spline) and the output flange part **1112** is fabricated as a single part. There are several distinct advantages of this: higher load capacity, lower weight, easier assembly, better quality, lower tolerances, less space requirements, less cost. This kind of integration is normally not thought of because the internal bearings are normally provided as a separate part from specialized suppliers. Also, the internal toothed gear (circular spline part) is highly specialized fabrication from few suppliers and it is considered necessary to add a separate output flange to interface the strain wave gear to the rest of the application.

The strain wave gear may also comprise first and second end plates (not shown). The first end plate may be arranged at the input side of the strain wave gear above the annular boss **1110** of the flex spline and comprise an opening allowing the input shaft **1111** to pass through the first end plate. The input shaft may be rotatably supported by the first and second end plates via bearings. The second end plate may be arranged at the output side of the strain wave gear at the end surfaces of the inner ring and comprises an opening allowing the input shaft and outwardly protruding output flange to pass through the second end plate.

FIGS. **12A** and **12B** illustrate a strain wave gear **1201** according to the present invention, where FIG. **12A** is a perspective view of the strain wave gear with one half of the strain wave gear cut away and FIG. **12B** is a cross-sectional view of the strain wave gear. The strain wave gear comprises an outer ring **1202**, an inner ring **1203**, a flex spline **1204** and a wave generator **1205**.

12

As describe previously the outer ring **1202** and outer ring **1203** are formed as annular shaped bodies. The inner ring **1203** is rotatable arranged in the central opening of the outer ring **1202** and the flex spline **1204** is arranged in the central opening of the inner ring **1202**. The inner ring **1203** comprises an internally toothed gear **1206** arrange at the inner wall of the inner ring and facing the central opening of the inner ring. The inner ring is rotatably arranged in the outer ring via an internal bearing **1207**.

The internal bearing **1207** is embodied as a cross roller bearing where the outer racer **1213** is integrally formed in the outer ring **1202**. The inner racer **1214** of the cross roller bearing **1207** is provided as a separate part and one end of the inner ring **1203** is coaxially connected to the inner racer **1214**. The inner ring **1203** and inner racer **1214** are thus consecutively arrange along the axis of rotation of the inner ring. The inner ring **1203** and the inner racer **1214** can be connected using any kind of fasteners such as screws, rivets, nails, click/snap mechanisms, adhesive, welding, press fit or any other kind of means for fixing the inner ring **1203** and the inner racer **1214** in relation to each other.

The flex spline **1204** is formed as a flexible cylindrical body, arranged in the inner ring and comprises an external toothed gear **1208**. The external toothed gear is configured to at least partially intermesh with the internal toothed gear **1206**. The flex spline comprises an annular diaphragm **1209** formed integrally with the cylindrical body and extending outwardly in relation to the cylindrical body. The annular diaphragm **1209** comprises and annular boss **1210** formed integrally on a circumferential outer peripheral edge of the diaphragm. The annular boss **1210** is fixed to the outer ring **1202** using any kind of fasteners such as screws, rivets, nails, click/snap mechanisms, adhesive, welding or any other kind of means for fastening the annular boss to the outer ring. Consequently, the inner ring is arranged between the outer ring **1202** and the cylindrical body of the flex spline **1204**. The external gear teeth **1208** are formed at the other end of the cylindrical body and extend along the outer peripheral surface of the cylindrical body. The wave generator **1205** is rotatably arranged in the flex spline **1204** and rotatable by a hollow input shaft **1211**. The input shaft is configured to rotate the wave generator in relation to the flex spline and the wave generator is upon rotation configured to flex the flexible cylindrical body in a radial direction to partly mesh the external toothed gear **1208** with the internally toothed gear **1206**. In the illustrated embodiment the wave generator is provided as an elliptical wave generator as known in the art of strain wave gears. The number of teeth of the internal toothed gear and the external toothed gear are different and rotation of the wave generator moves meshing positions of the gears in a circumferential direction causing the inner ring to rotate in relation to the outer ring. The input shaft can for instance be driven by a motor whereby the strain wave gear forms a transmission system between the motor and output side of the strain wave gear.

A part of the inner ring extends out of said outer ring and comprises an outwardly protruding output flange **1212**. The outwardly protruding output flange extends outwardly in relation to the inner ring and towards the outer ring. Providing the inner ring with an outwardly protruding output flange makes it possible to connect the strain wave gear directly to the object to be driven by the strain wave gear, whereby the previously described advantages and benefits can be achieved. In this embodiment the outwardly protruding output flange is provided as one of the component flanges of the releasable joint assembly disclosed by WO 2018/130447 incorporated herein by reference.

13

The input shaft 1211 extends through the flex spline 1204 and is rotatable supported by the inner ring 1203 via an input shaft support bearing 1216. The input shaft support bearing 1216 comprises an outer racer 1217 arranged in the inner ring 1203 and inner racer 1218 wherein the input shaft 1211 is arranged. The input shaft 1211 comprises an outer annular flange 1221 configured to support the input shaft support bearing 1216. A seal (not shown) can be arranged in a cavity 1231 between the inner ring 1202 and outer ring 1203. The seal can prevent lubrication provided inside the internal bearing 1207 from leaking out. The sealing can be provided as any kind of sealing known from strain wave gears.

The strain wave gear comprises a first end plate 1232 arranged at the input side of the strain wave gear above the annular boss 1210 of the flex spline and comprise an opening allowing the input shaft 1211 to pass through the first end plate. The input shaft 1211 is rotatably supported by the end plate via a support bearing 1233. The support bearing 1233 comprises an outer racer 1234 arranged in the first end plate 1232 and an inner racer 1235 wherein the input shaft 1211 is arranged. The outer racer 1234 is supported by an inner annular flange 1236 of the first end plate.

The strain wave gear 1201 comprises encoder reader 1222 disposed on the outer ring 1202 and an encoder track 1223 disposed on the inner ring 1203, where the encoder reader comprises an encoder PCB (printed circuit board) 1224 comprising electronics for controlling and reading signals to and from an encoder head 1225. The encoder PCB 1224 is arranged at the end of the outer ring 1202 opposite the end where the annular boss 1210 is fixed to the outer ring 1202. The encoder track 1223 is provided as an annulus and is arranged on an outer annular flange 1227 of the inner ring 1202. The outer annular flange 1227 of the inner ring comprises a surface facing away from the end of the strain wave gear where the annular boss 1210 is attached to the outer ring 1202. The encoder head 1225 is arranged on the encoder PCB 1224 and faces the surface facing of the outer annular flange facing away from the end of the strain wave gear the annular boss 1210 is attached to the outer ring.

FIG. 13 illustrates a simplified cross-sectional view of a robot joint 1340 comprising a strain wave gear according to the present invention. The robot joint 1340 can form part of a robot arm comprising a plurality of robot joints and is connectable to at least another robot joint 1340' via an output flange 112. The other robot joint 1340' is illustrated identically to first robot joint 1340 and similar features have been given the same reference numbers with a prime sign after the reference number. In the illustrated embodiment the two robot joints are connected directly with each other, however it is to be understood that a robot link can be inserted between the robot joints. The robot joint comprises a joint motor 1341 arranged in a robot joint housing 1342. The joint motor comprises a motor axle 1343 rotatable around a motor axis and the motor axle is via a strain wave gear 901 configured to rotate the output flange 112 in relation to the robot housing 1342 by rotating a wave generator 105 of the strain wave gear. In the illustrated embodiment the strain wave gear is provided as the strain wave gear 901 illustrated in FIG. 9, however it is to be understood that any of the previously described strain wave gears or combinations thereof can be provided as the strain wave gear of the robot joint. For the sake of simplicity of the drawing the elements of the strain wave gear 901 has not been provided with all of the reference numbers illustrated in FIG. 9. The motor axle is provided as input shaft to the strain wave gear and rotates the wave generator 105 and is hollow to allow wires to be lead through the robot joints and robot arm.

14

The robot housing comprises an input flange 1344 configured to connect with the output flange of another robot joint or robot link. The output flange 112 of the robot joint is connected to the input flange 1344' of the other robot joint 1340'. The input flanges 1344, 1344' are formed as outwardly protruding input flanges and can be clamped to an output flange using an annular clamp 1345. Output flange 112 of robot joint 1340 is thus connected to input flange 1344' of robot joint 1340'. However, it is to be understood that other mechanism for connecting the output flange and input flanges of two robot joints, for instance click/snap mechanism, screws, threads etc. Providing the robot joint with the strain wave gear according to the present invention results in the advantages and benefits described previously and makes it possible to provide a more reliable and less expensive robot joint.

The following paragraphs-present an alternative disclosure of the present invention with reference to FIGS. 14A and 14B. FIG. 14A illustrates a cross sectional view of an example of a wave gear drive according to the present invention and FIG. 14B illustrates a cross sectional view of a section the wave gear drive shown in FIG. 14A. It is noted that the systematic of the figure references deviates from the previous paragraphs and figures.

In order to solve the above and other objects, according to the present invention, there is in a first aspect provided a strain wave gear drive comprising:

- an outer ring (1) of output bearing in strain wave gear;
 - inner ring (2) of output bearing in strain wave gear;
 - an output flange (5);
 - a flexible spline part (3) with an external gear positioned inside the internal gear; and
 - a circular spline part (4) with an internal gear, and
 - a wave generator disposed within said flexible spline part for deflecting the part (3) in radial direction for partially engaging the external gear with the internal gear;
- wherein the inner ring (2) and the circular spline part (4) constitutes a single piece in combination with the output flange of strain wave gear (5) being coaxially disposed.

The outer ring (1) and/or the inner ring (2) is/are formed from a lightweight material. Also, the internal and external gears can be toothed gears. The flexible spline part (3) may have a cylindrical body portion, an annular diaphragm formed integrally with said body portion in a condition closing one end opening of said body portion, a boss integrally formed with said diaphragm and located at the center of the latter, and external gear teeth formed at the other end opening of said body portion and extending along the outer peripheral surface. A cross roller bearing may be disposed on the outer periphery of the cylindrical body portion of the flexible spline part (3), and the outer ring (1) fixed to one end plate via an annular boss and the inner ring (2) fixed to another end plate via the circular spline part (4).

As noted above the present invention is also directed to a solution embodying an encoder placed inside the strain wave gear. In that respect the following two exemplary alternative configurations apply:

- i) the reading head (6) of the encoder is disposed on the outer ring (1) of the output bearing and the read track (7) is disposed on the inner ring (2) of output bearing; and
- ii) the encoder is placed inside the strain wave gear so that the reading head (6) of the encoder is disposed on the inner ring (2) of the output bearing and the read track (7) is disposed on the outer ring (1) of output bearing.

15

In a second aspect the present invention provides a strain wave gear drive with an encoder inside, said drive comprising:

- outer ring (1) of output bearing in strain wave gear;
- inner ring (2) of output bearing in strain wave gear;
- a circular spline part (4) with internal gear and which is rotatable around a rotational axis;
- a flexible spline part (3) with an external gear positioned inside the internal gear which is concentrically disposed within the circular spline part (4);
- a wave generator disposed within said flexible spline part for deflecting the part (3) in radial direction for partially engaging the external gear with the internal gear;
- a ball bearing flexible in the radial direction disposed between the wave generator and the flexible spline part (3),

wherein an encoder is placed inside the strain wave gear so that the reading head (6) of the encoder is disposed on the outer ring (1) of the output bearing and the read track (7) is disposed on the inner ring (2) of output bearing.

In an alternative of the second aspect of the present invention there is provided a strain wave gear drive with an encoder inside, said drive comprising:

- outer ring (1) of output bearing in strain wave gear;
- inner ring (2) of output bearing in strain wave gear;
- a circular spline part (4) with internal gear and which is rotatable around a rotational axis;
- a flexible spline part (3) with an external gear positioned inside the internal gear which is concentrically disposed within the circular spline part (4);
- a wave generator disposed within said flexible spline part for deflecting the part (3) in radial direction for partially engaging the external gear with the internal gear;
- a ball bearing flexible in the radial direction disposed between the wave generator and the flexible spline part (3),

wherein an encoder is placed inside the strain wave gear so that the reading head (6) of the encoder is disposed on the inner ring (2) of the output bearing and the read track (7) is disposed on the outer ring (1) of output bearing.

FIGS. 14A and 14B show a cross section of a wave gear drive according to the present invention. The wave gear drive has first and second end plates and positioned in a prescribed gap along an axial direction thereof. A cross roller bearing (or a normal ball bearing) is positioned at a radially outer side between the first and second end plates. An input rotational shaft is arranged passing through the first and second end plates along the axial direction. The input rotational shaft is rotatably supported by these end plates via ball bearings and mounted on circumferential inner surfaces and of the end plates, respectively. The cross roller bearing has an inner race which is integrally formed with a rigid internal gear. More specifically, internal teeth of the rigid internal gear are formed on a circumferential inner surface of the inner race. Inside the internal teeth, there is provided a flexible external gear having external teeth. An elliptical wave generator may be inserted into the flexible external gear. The external gear has a cylindrical body, a circular diaphragm extending outward in a radial direction from one open end of the body, a circular boss formed integrally on a circumferential outer peripheral edge of the diaphragm. The external teeth are formed on a circumferential outer surface of the other open end portion of the body. The wave generator comprises an elliptical rigid cam plate and a wave bearing fixed on the cam plate.

The encoder parts (6 and 7) can be mounted directly on the output bearing parts without need for special platforms/

16

brackets or other support parts. This saves weight and cost. The reading distance between the encoder read head (6) and the encoder read track (7) will be very precise without the need for manual adjustment. This is an advantage because of easier assembly and lower cost. The precision and accuracy of the encoder readout can be higher than in other designs because of the precisely controlled reading distance between encoder parts. This is a big advantage in many applications where precision and accuracy is needed. There is no need for mechanical transmission parts to drive the encoder disc relatively to the output from the gear. This would result in lower precision and accuracy plus added cost and quality issues. The encoder parts are mechanically well protected by sitting inside the gear. This is an advantage in applications with harsh environments that could damage the delicate electronics. The encoder read track (7) can be of large diameter which raises precision and accuracy.

The Encoder PCB and electronics can be coated with a suitable coating to make sure it does not release any chemical agents to the grease/oil inside the gear. The encoder reading principle can be selected specially for use where grease/oil can be present e.g. magnetic vs optical. The reading track can be a physical pattern in the surface of the output bearing material (machined, etched, laser engraved etc.) to avoid extra parts inside the gear. The wire from the encoder PCB can be a flex wire exiting from the edge of the PCB, to make it easier to place gaskets around the PCB.

The gear will be able to drive higher loads on the output because the output is an integral part of the output bearing and circular spline. This is an advantage for most applications. The output flange geometry will be very precisely centered with respect to the gear axis because there are no assembly tolerances from separate parts being screwed together. The gear will be easier and quicker to assemble because no screws are needed to assemble the separate parts. The quality and reliability of the gears will be higher because there is no risk of screws breaking or becoming loose and there is no risk of flanges slipping if screws are not tightened correctly. The weight of the gear will be lower because the integration of parts can be optimized for strength, where the separate parts need excessive material to form support geometry and centering rims, and because no screws are needed. The cost of the gear will be lower because of fewer parts to be fabricated and less material use.

The strain wave gear drive illustrated in FIGS. 14A and 14B can also be defined by the following statements in roman numbers:

Statement I: A strain wave gear drive comprising:

- outer ring (1) of output bearing in strain wave gear;
- inner ring (2) of output bearing in strain wave gear;
- an output flange (5);
- a flexible spline part (3), such as a cup type flex spline or silk hat flex spline, with an external gear positioned inside the internal gear; and
- a circular spline part (4) with an internal gear, wherein the inner ring (2) and the circular spline part (4) constitutes a single piece in combination with the output flange (5) being coaxially disposed.

Statement II: Strain wave gear of statement I, wherein a wave generator is disposed within said flexible spline part for deflecting the part (3) in radial direction for partially engaging the external gear with the internal gear

Statement III: Strain wave gear of statement I or II, wherein flexible spline part (3) has a cylindrical body portion, an annular diaphragm formed integrally with said body portion in a condition closing one end opening of said body portion, a boss integrally formed with said diaphragm

and located at the center of the latter, and external gear teeth formed at the other end opening of said body portion and extending along the outer peripheral surface.

Statement IV: Strain wave gear of statement III, wherein a cross roller bearing is disposed on the outer periphery of the cylindrical body portion of the flexible spline part (3), and the outer ring (1) fixed to one end plate via an annular boss and the inner ring (2) fixed to another end plate via the circular spline part (4).

Statement V: Strain wave gear of any one of the statements I to IV, wherein an encoder is placed inside the strain wave gear so that the reading head (6) of the encoder is disposed on the outer ring (1) of the output bearing and the read track (7) is disposed on the inner ring (2) of output bearing.

Statement VI: Strain wave gear of any one of the statements I to IV, wherein an encoder is placed inside the strain wave gear so that the reading head (6) of the encoder is disposed on the inner ring (2) of the output bearing and the read track (7) is disposed on the outer ring (1) of output bearing.

Statement VII: A strain wave gear drive with an encoder inside, said drive comprising:

- outer ring (1) of output bearing in strain wave gear;
 - inner ring (2) of output bearing in strain wave gear;
 - a circular spline part (4) with internal gear and which is rotatable around a rotational axis;
 - a flexible spline part (3) with an external gear positioned inside the internal gear which is concentrically disposed within the circular spline part (4);
 - a ball bearing flexible in the radial direction disposed between the wave generator and the flexible spline part (3),
- wherein an encoder is placed inside the strain wave gear so that the reading head (6) of the encoder is disposed on the outer ring (1) of the output bearing and the read track (7) is disposed on the inner ring (2) of output bearing.

Statement VIII: Strain wave gear drive of statement VII, wherein a wave generator disposed within said flexible spline part for deflecting the part (3) in radial direction for partially engaging the external gear with the internal gear.

Statement IX: Strain wave gear of statement VII or VIII, wherein the inner ring (2) and the circular spline part (4) constitutes a single piece being coaxially disposed.

Statement X: Strain wave gear of statement VII or VIII further comprising an output flange (5), wherein the inner ring (2) and the circular spline part (4) constitutes a single piece in combination with the output flange (5) being coaxially disposed.

Statement XI: A strain wave gear drive with an encoder inside, said drive comprising:

- outer ring (1) of output bearing in strain wave gear;
 - inner ring (2) of output bearing in strain wave gear;
 - a circular spline part (4) with internal gear and which is rotatable around a rotational axis;
 - a flexible spline part (3) with an external gear positioned inside the internal gear which is concentrically disposed within the circular spline part (4);
 - a ball bearing flexible in the radial direction disposed between the wave generator and the flexible spline part (3),
- wherein an encoder is placed inside the strain wave gear so that the reading head (6) of the encoder is disposed on the inner ring (2) of the output bearing and the read track (7) is disposed on the outer ring (1) of output bearing.

Statement XII: Strain wave gear drive of statement XI, wherein a wave generator disposed within said flexible spline part for deflecting the part (3) in radial direction for partially engaging the external gear with the internal gear.

Statement XIII: Strain wave gear of statement XI or XII, wherein the inner ring (2) and the circular spline part (4) constitutes a single piece being coaxially disposed.

Statement XIV: Strain wave gear of statement XI or XII further comprising an output flange (5), wherein the inner ring (2) and the circular spline part (4) constitutes a single piece in combination with the output flange (5) being coaxially disposed.

Statement XV: A strain wave gear drive comprising:
 outer ring (1) of output bearing in strain wave gear;
 inner ring (2) of output bearing in strain wave gear;
 an output flange (5) with an internal gear;
 a flexible spline part (3), such as a cup type flex spline or silk hat flex spline, with an external gear positioned inside the internal gear; and
 a circular spline part (4),
 wherein the inner ring (2) and the circular spline part (4) constitutes a single piece in combination with the output flange (5) being coaxially disposed.

BRIEF DESCRIPTION OF FIGURE REFERENCES

FIGS. 1-13:

101, 201, 301, 401, 501, 601, 701, 801, 901, 1001, 1101, 1201, 901'	strain wave gear
102, 202, 902, 1002, 1102, 1201	outer ring
103, 303, 403, 603, 1003, 1103, 1203	inner ring
104, 1104, 1204	flex spline
105, 1105, 1205, 105'	wave generator
106, 1106, 1206	internal toothed gear
107, 207, 307, 407, 1107, 1207	internal bearing
108, 1108, 1208	external toothed gear
109, 1109, 1209	annular diaphragm
110, 1110, 1210	annular boss
111, 511, 611, 1111, 1211	input shaft
112, 1112, 1212, 112'	outwardly protruding output flange
113, 213, 1113, 1213	outer racer of internal bearing
114, 214, 314, 414, 1114, 1214	inner racer internal bearing
516, 1116, 1216	input shaft support bearing
517, 1117, 1217	outer racer of input shaft support bearing
518, 1118, 1218	inner racer of input shaft support bearing
1119	seal
620, 1120	inner annular flange of inner ring
1121, 1221	outer annular flange of input shaft
722, 822, 1022, 1122, 1222	encoder reader
723, 823, 1023, 1123, 1223	encoder track
724, 824, 1024, 1124, 1224	encoder reader PCB
725, 825, 1025, 1125, 1225	encoder reader head
827, 1027, 1227	outer annular flange of inner ring
928, 1028, 1128, 1228	inner annular flange of outer ring
1130, 1230	gaskets
1231	cavity
1232	first end plate
1233	input shaft support bearing
1234	outer racer of support bearing
1235	inner racer of support bearing
1236	inner annular flange of end plate
1340, 1340'	robot joint
1341, 1341'	joint motor
1342, 1342'	joint housing
1343, 1343'	joint motor
1344, 1344'	input flange

19

FIGS. 14A and 14B

the outer ring of output bearing in strain wave gear (1),
the inner ring of output bearing in strain wave gear (2),
the flex spline part of strain wave gear (3),
the circular spline part of strain wave gear (4),
the output flange of strain wave gear (5),
the encoder read head (6),
the read track for encoder (7), and
the gasket for encoder PCB (8).

The invention claimed is:

1. A strain wave gear comprising:
an input shaft configured for rotation;
an outer ring;
an inner ring at least partly within the outer ring, the inner ring being configured for rotation within the outer ring, the inner ring comprising first teeth;
a spline at least partly within the inner ring, the spline comprising second teeth, the second teeth for at least partly meshing with the first teeth, a part of the spline being fixed to the outer ring;
a wave generator within the spline, the wave generator being connected to the input shaft and configured to rotate in response to a rotation of the input shaft;
wherein, in response to the rotation of the input shaft, the wave generator is configured to cause at least part of the spline to flex toward the outer ring to cause at least part of the second gear to mesh with at least part of the first teeth and thereby enable the inner ring to rotate relative to the outer ring;
wherein the inner ring comprises an encoder track; and
wherein the outer ring comprises an encoder circuit board and an encoder head on the encoder circuit board, the encoder head being configured to obtain information based on the encoder track, the information being indicative of a position of the inner ring relative to the outer ring, the encoder circuit board comprising electronics for obtaining data based on the information from the encoder head.
2. The strain wave gear of claim 1, wherein the encoder head is configured to face the inner ring; and
wherein the encoder track is configured to face the encoder head.
3. The strain wave gear of claim 1, wherein the inner ring comprises a flange that extends towards the outer ring and past at least part of the outer ring; and
wherein the encoder circuit board is at an end of the outer ring that faces the flange.
4. The strain wave gear of claim 1, wherein the outer ring comprises a first flange having a surface holding the encoder circuit board with the encoder head on the encoder circuit board; and
wherein the inner ring comprises a second flange having a surface holding the encoder track.
5. The strain wave gear of claim 1, wherein the encoder head is configured to face the encoder track.
6. The strain wave gear of claim 1, further comprising:
an internal bearing between the inner ring and the outer ring, the internal bearing for supporting rotation of the inner ring relative to the outer ring.
7. The strain wave gear of claim 1, wherein a cross-section of the outer ring is rectangular in shape.
8. The strain wave gear of claim 1, further comprising:
an internal-toothed gear comprising the first teeth; and
an external-toothed gear comprising the second teeth.
9. The strain wave gear of claim 1, wherein the inner ring comprises a flange that extends outward from the inner ring beyond at least part of the outer ring.

20

10. The strain wave gear of claim 1, wherein the encoder track comprises a magnetic track; and
wherein the encoder head comprises a magnetic reader configured to obtain the information by reading the magnetic track.

11. The strain wave gear of claim 10, wherein the magnetic reader comprises at least one Hall sensor.

12. The strain wave gear of claim 1, wherein the encoder track comprises indicators; and
wherein the encoder head comprises an optical reader configured to obtain the information by reading the indicators.

13. The strain wave gear of claim 1, wherein the input shaft extends beyond the outer ring.

14. A strain wave gear comprising:
an input shaft configured for rotation;
an outer ring;
an inner ring at least partly within the outer ring, the inner ring being configured for rotation within the outer ring, the inner ring comprising first teeth;
a spline at least partly within the inner ring, the spline comprising second teeth, the second teeth for at least partly meshing with the first teeth;
a wave generator within the spline, the wave generator being connected to the input shaft and configured to rotate in response to a rotation of the input shaft;
wherein, in response to the rotation of the input shaft, the wave generator is configured to cause at least part of the spline to flex toward the outer ring to cause at least part of the second teeth to mesh with at least part of the first teeth and thereby enable the inner ring to rotate relative to the outer ring;

wherein the inner ring comprises an encoder track;
wherein the outer ring comprises an encoder circuit board and an encoder head on the encoder circuit board, the encoder head being configured to obtain information based on the encoder track, the information being indicative of a position of the inner ring relative to the outer ring, the encoder circuit board comprising electronics for obtaining data based on the information from the encoder head;

wherein the spline comprises a cylindrical body and an annular diaphragm formed integrally with the cylindrical body, the annular diaphragm extending outwardly from the cylindrical body in a direction away from the input shaft; and

wherein the encoder circuit board is below the annular diaphragm; and
wherein the encoder circuit board is between the annular diaphragm and a top of the inner ring.

15. The strain wave gear of claim 14, wherein the encoder track is on a part of the inner ring facing the annular diaphragm.

16. The strain wave gear of claim 15, wherein the encoder track is on a top of the inner ring facing the annular diaphragm.

17. The strain wave gear of claim 14, wherein the outer ring comprises a flange that holds the encoder circuit board with the encoder head on the encoder circuit board.

18. The strain wave gear of claim 17, wherein the encoder head is configured to face the encoder track.

19. The strain wave gear of claim 14, further comprising:
an input shaft support bearing between the input shaft and the inner ring.

20. The strain wave gear of claim 19, further comprising:
an internal bearing between the input ring and the output ring.

21

21. The strain wave gear of claim **14**, wherein the input shaft extends beyond the outer ring.

22. A strain wave gear comprising:

an input shaft configured for rotation;

an outer ring;

an inner ring at least partly within the outer ring, the inner ring being configured for rotation within the outer ring, the inner ring comprising first teeth;

a spline at least partly within inner ring, the spline comprising second teeth, the second teeth for at least partly meshing with the first teeth;

a wave generator within the spline, the wave generator being connected to the input shaft and configured to rotate in response to a rotation of the input shaft;

wherein, in response to the rotation of the input shaft, the wave generator is configured to cause at least part of the spline to flex toward the outer ring to cause at least part of the second teeth to mesh with at least part of the first teeth and thereby enable the inner ring to rotate relative to the outer ring;

22

wherein the inner ring comprises an encoder track;

wherein the outer ring comprises an encoder circuit board and an encoder head on the encoder circuit board, the encoder head being configured to obtain information based on the encoder track, the information being indicative of a position of the inner ring relative to the outer ring, the encoder circuit board comprising electronics for obtaining data based on the information from the encoder head;

wherein the spline comprises a cylindrical body and an annular diaphragm formed integrally with the cylindrical body, the annular diaphragm extending outwardly from the cylindrical body in a direction away from the input shaft; and

wherein the encoder circuit is board at an end of the outer ring that is away from the annular diaphragm.

23. The strain wave gear of claim **22**, wherein the input shaft extends beyond the outer ring.

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